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Shuttle Upper Atmosphere Mass Spectrometer (SUMS): Data Analysis System and 61-C Flight Data Results

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Abstract

This report presents results and status of work performed under contract NAS1-16385, Phases II and III, covering software development and flight data analysis for the Shuttle Upper Atmosphere Mass Spectrometer (SUMS) experiment. A descriptive summary of the SUMS Flight Data Reduction and Analysis System (software) is presented, including details of the inlet reduction algorithm. Static and dynamic calibration test procedures are discussed and results of the tests are presented. A discussion of ongoing analysis efforts is included. The results of flight data analysis for the SUMS 61-C (STS-32) mission are attached to this report. This was the only SUMS flight during the contract period and failure of the protection valve caused loss of science data.

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SECTION 1 - INTRODUCTION

This report covers work performed under Phase II and III of contract NAS1-16385 ending March 31, 1987. (Phase I results were reported in Reference 1.) It includes a description of the SUMS Flight Data Reduction and Analysis System, a description of the SUMS calibration technique, and a discussion of support analyses conducted during SUMS development. The interim final report for the only SUMS flight (STS-32, 61-C) was completed in May, 1986, and is included with this report as Attachment A.

The procedures and software necessary for the reduction and analysis of SUMS calibration test data were completed prior to the test performance at the University of Texas-Dallas (UTD). The test data were processed and analyzed at LaRC and the calibration constants derived from this analysis were incorporated into the flight data reduction software.

The SUMS Flight Data Reduction and Analysis System software was completed before the launch of Shuttle Orbiter Columbia, OV-102, on the 61-C mission in January, 1986. Prior to this first flight, the software system had been checked out using the OEX-CCT tapes recorded during the OEX Integrated Systems Test (IST) at NASA/JSC and during the OEX Integrated Vehicle Test (IVT) at NASA/KSC.

Flight data from the 61-C mission were processed with virtually no problems and the spectral data from SUMS were available for review within 24 hours of receipt of data tapes at LaRC. Analysis of the 61-C flight data showed an apparent failure of the instrument to measure any ambient gas samples and subsequent hardware tests confirmed that the protection valve had failed closed.

During the STS stand-down since mission 51-F, some software enhancement based on 61-C experience has been accomplished. Analysis of HIRAP derived atmosphere density data from ten flights has been performed with the objective of ensuring that the SUMS software can accommodate the actual density variations occurring during flight. The large gradients observed in some HIRAP results could present a problem for SUMS with respect to dynamic response if these gradients are in fact atmospheric. Also, techniques for combining angular acceleration data derived from the ACIP rate gyros with the SUMS data have been developed. This capability will expand the aerodynamic analysis to include moment coefficient as well as force coefficients.

SECTION 2 - SUMS FLIGHT DATA REDUCTION AND ANALYSIS SYSTEM

This section provides an overview of the data flow and software programs developed for reduction and analysis of SUMS flight data. Part of the system is written in FORTRAN for the LaRC Central Computer Complex. Partial reduction of flight data is accomplished on the central computer and the results are transferred to the HP 9836 system in Bldg. 1232, Room 246-B, via nine-track magnetic tapes. The remainder of data reduction and analysis is performed on the HP system.

2.1 Data Processing Flow and Program Descriptions

Figures 1, 2, and 3 are flow charts of the SUMS Flight Data Reduction and Analysis System software program interfaces. The raw OEX-PCM data is received from NASA-JSC on magnetic computer tapes which are written in packed form, one PCM cycle per record. Any of the various OEX-PCM formats can be accommodated but format 4 is currently in place on the OV-102 PCM. This format contains 72 data words (8-bits) per mainframe with the standard 64 mainframes per data cycle.

The following paragraphs summarize the input, function, and output of each of the twenty-three primary programs which comprise the flight data reduction and analysis system. Current listings of these programs are maintained with the HP system library in Bldg. 1232.

2.1.1 SUMSTRP

SUMSTRP buffers in each PCM data cycle as a record and then unpacks the record to retrieve the 4608 eight-bit PCM words. The IRIG-B time code for each mainframe is decoded and the SUMS words in channels 47, 48, and 49 are stripped out. These data are output in binary format to magnetic tape, three time words and three SUMS words per mainframe.

2.1.2 SUMSRED

SUMSRED is the major program in the central computer part of the SUMS system. It reads the SUMS PCM data tape and processes the data on the basis of SUMS scan intervals of five seconds. The time words at the beginning of a SUMS scan are converted to GMT seconds to establish the scan reference time. Fill words containing the SUMS instrument status flags are identified and a running record of each status flag is maintained. Changes in status are output to the Instrument Status Summary. UAMS engineering data is stripped from the word 47, 48 stream and output as part of the SUMS scan data on the Science and Engineering Data (SED) tape. SUMS engineering data in channel 49 are decalibrated and output to the High Frequency Engineering (HFE) data file. Finally, the SUMS science data words are decalibrated and output in units of ion current to the SED tape. During this entire process, a running record of data gaps is maintained and output as the Data Status Summary.

2.1.3 CONVSED

CONVSED reads the SED tape and outputs the data words to a local file via a formatted write. Ten data words are written to each of 38 records of 132 characters each, representing a complete SUMS scan of science and engineering data. The local formatted output file is processed via the system routine TCOPY to create an output 9-track tape containing 132 column card images in ASCII. This tape serves as the data interface between the central computer facility and the HP 9836 system for SUMS science and engineering data.

2.1.4 SCANOUT

SCANOUT reads the SED file and prints selected scans for review and analysis. The print format includes all science, engineering, and status data for a complete scan.

2.1.5 PCMSEG

PCMSEG reads the SUMS PCM file and outputs selected segments of the raw PCM data to a 9-track interface tape for transport to the HP 9836 system. This capability facilitates the reconstruction of SUMS scans which may be out of sync due to data gaps in the CCT.

2.1.6 CONVHFE

CONVHFE performs a similar function to that of CONVSED in that the high frequency engineering data is output to a 9-track interface tape for transport to the HP 9836 system.

2.1.7 SUMPATH

This program reads the Postflight Altitude and Trajectory History (PATH) tape for orbital flight and strips the parameters useful to SUMS analysis. Data is output to a 9-track interface tape.

2.1.8 SUMSBET

SUMSBET strips reentry trajectory data from the Best Estimated Trajectory (BET) tapes and records the data on a 9-track interface tape.

2.1.9 SUMS9TRK, PATH9TRK, BET 9TRK

These programs are similar in that they read the 9-track interface tapes for SUMS science and engineering data, PATH orbital trajectory and attitude data, and reentry BET trajectory and attitude data, respectively, and convert the ASCII formatted data to internal HP floating point numbers. The results are stored in the appropriate files on the HP hard disc.

2.1.10 SUMS

SUMS inputs the SUMS science and engineering data from the hard disc and "picks" the appropriate ion current peak from the 360 high mass steps and 72 low mass steps for each of the specified integer AMU values. The results are stored on the appropriate "PEAKS" file. This program also plots all the ion current peaks for each scan as a spectral plot versus AMU or step number.

2.1.11 READPEAKS

READPEAKS plots the selected peaks versus time for the entire reentry or orbital sequence. It also calculates the mass fraction for each peak with respect to total mass and outputs this parameter with time and the AMU 28 ion current.

2.1.12 I28_POOL

I28_POOL reads the I28 file and updates the SUM_POOL_n file on hard disc, where n = serial number for the respective SUMS flight. The times of range valve closure, inlet valve closure and entry interface are updated if desired.

2.1.13 BET_POOL

BET_POOL reads trajectory data at one second measurement intervals from the BET file and SUMS scan reference times at five second intervals from the SUMS_POOL_n file. Trajectory parameters are interpolated to SUMS scan reference times and stored on the SUM_POOL_n file.

2.1.14 PATH_POOL

PATH_POOL reads the orbital data at one second intervals on the PATH file and SUMS scan reference times at five second intervals on the SUM_POOL_n file. Trajectory parameters are interpolated to SUMS scan reference times and stored on the SUM POOL_n file.

2.1.15 TW_POOL

TW_POOL replaces the wall temperature (T_w) on the SUM_POOL_n file. Scan reference times and altitudes are read from the POOL file. T_w is interpolated to scan reference times from table of T_w versus altitude in the program. The T_w table is updated for each flight either from preflight predictions for quick-look data reduction or from flight measurements for final data reduction.

2.1. 16 TINF_POOL

TINF_POOL replaces the free-stream temperature on the SUM_POOL_n file. Scan reference times and altitudes are read from the POOL file. Free-stream temperature is calculated from the 1976 U.S. Standard Atmosphere kinetic temperature equations as a function of altitude at each scan reference time. Results are stored on the POOL file. This program can be updated in the future to accommodate other kinetic temperature models if desired.

2.1.17 MW_POOL

MW_POOL reads scan reference times and altitude from the SUM_POOL_n file. Mean molecular weight from the 1976 U.S. Standard Atmosphere equations is calculated for each scan reference time and output to the POOL file. This program can be modified to calculate mean molecular weight from the actual SUMS flight measurements for final flight data reduction.

2.1.18 POOL_PLOT

POOL_PLOT is a plot utility program which plots any selected parameter in the POOL file versus any other parameter in the file.

2.1.19 INRED_RVO

INRED_RVO calculates the partial AMU 28 orifice pressure from SUMS AMU 28 ion current measurements for the data interval when the range valve is open. The process for this calculation is described in detail in paragraph 2.2. Output of the reduced partial orifice pressure is to an intermediate file for input to INRED_RVC.

2.1.20 INRED_RVC

INRED_RVC accomplishes the same task as INRED_RVO except the data interval is during the range valve open period. Optional plotting of results is available.

2.1.21 SUMSAERO

SUMSAERO performs the following functions:

- computes dynamic pressure from reduced orifice pressure and flow field algorithm
- computes free stream density from dynamic pressure and velocity
- computes Knudson number
- computes viscous interaction parameter

All I/O for SUMSAERO is via keyboard on prompt or from the SUM_POOL_n file. Results are available also through a plot option.

2.2 Inlet Reduction Process

This paragraph describes the algorithm for reduction of SUMS flight measurements to inlet orifice pressure values. A lumped-parameter electrical network analogy was used to derive a math model of the SUMS system response to a time variant orifice pressure. This model was calibrated against the actual instrument response obtained from a series of static and dynamic calibration tests. It then provided the analytic basis for the inlet data reduction algorithm.

2.2.1 SUMS Analytic Model

The analytic model used to predict the SUMS response to a time variant orifice pressure is described in Reference 2. The model is based on an electrical network analogy for which the differential equations describing the network response were solved. This solution was incorporated into a computer code which outputs the instantaneous SUMS ion source pressure for a given orifice pressure history. The code also outputs the ratio of predicted ion source pressure to the theoretical static ion source pressure at the given instantaneous orifice pressure. This parameter, referred to as the "fraction of static pressure", is a measure of the dynamic pressure lag of the SUMS inlet system. Since the fraction of static pressure is predicted to be as low as 0.70 during flight, compensation for dynamic lag in the data reduction process is necessary to avoid large errors in interpretation of the SUMS flight data.

The model equation for ion source pressure, P_{IS}, as a function of orifice pressure, P_{OR}, with P_{OR} varying as $P_o + kt$, is

$$P_{IS} = P_N(t) + AM\ (P_o + kt) + MBk$$

where $P_N(t)$ = natural response term (torr)

P_o = orifice pressure at $t = o$ (torr)

k = slope of orifice pressure with time (torr/sec)

t = time (sec)

A,B,M = coefficients dependent on network parameters (note: some elements of the network are functions of orifice pressure)

Since $P_N \rightarrow 0$ as $t \rightarrow \infty$ and $k = o$ for a constant or static orifice pressure, this equation reduces to

$$P_{IS} = AMP_{OR}$$

for the static case, with AM equal to the static pressure drop of the SUMS inlet system. The fraction of static pressure is then

$$R = \frac{P_{IS(DYN)}}{P_{IS(STAT)}} = \frac{P_N + AM\ (P_o + kt) + MBk}{AM\ (P_o + kt)}$$

$$= 1 + \frac{P_N + MBk}{AM\ (P_o + kt)}$$

which depends upon the natural response history described by P_N and the magnitude of the orifice pressure slope, k, for given system characteristics described by A, B, and M.

As previously stated, the coefficients A, B, and M depend upon the model network parameters. The network is defined by lumping the distributed conductances of the inlet system and the UAMS termination into five discrete resistive elements and lumping the distributed volumes of the system into four discrete capacitive elements. Errors associated with this approach are primarily in the "lumping" process and in the analytic assumptions behind the equations used to calculate conductance (Reference 3). Concern over the magnitude of these errors motivated the performance of a series of dynamic calibration tests which serve to benchmark the model against the actual system response.

2.2.2 Inlet System Flight Data Reduction Algorithm

The basic equation for the inlet system data reduction step is given in Reference 1 as

$$P_{OR} = \frac{P_{IS} + \Delta t\ \frac{B}{A}\ (\Delta\ P_N - \ \Delta P_{IS}) - P_N}{AM}$$

where Δt = the five second interval between successive samples of a given mass number (secs)

ΔP_N = change in natural response contribution to ion source pressure over Δt (torr)

ΔP_{IS} = change in total ion source pressure over Δt (torr).

P_{IS}, P_N = values of total ion source pressure and natural response contribution to ion source pressure at end of interval Δt (torr)

A problem arises at this point because SUMS provides the ion current produced by a given source pressure, but because of the addition of the inlet system the mass spectrometer is "closed" and must be calibrated indirectly for sensitivity in terms of ion current produced per unit <u>orifice</u> pressure. The source pressure is unknown and is never measured. This requires P_{IS} to be expressed in terms of P_{OR} in its static relationship as developed in 2.2.1,

$$P_{IS} = AM\ P_{OR}.$$

Static calibration determines the sensitivity coefficient, S, which is the ratio of ion current produced per unit orifice pressure. This gives

$$P_{IS} = AM \frac{I}{S}\ ; \quad \Delta P_{IS} = AM \frac{\Delta I}{S}$$

Substituting these expressions in the reduction equation gives

$$P_{OR_2} = \frac{1}{S}\left[I_2 - \frac{B}{A}\ \frac{(I_2-I_1)}{\Delta t}\right] + \frac{1}{AM}\left[\frac{B}{A}\ \frac{(P_{N_2} - P_{N_1})}{\Delta t} - P_{N_2}\right]$$

where subscripts 1 and 2 refer to any two successive flight data measurements at the SUMS scan interval of five seconds, Δt. This is the final form of the inlet reduction algorithm as programmed in the SUMS flight data reduction software system.

2.2.3 Inlet Data Reduction Logic

The inlet reduction algorithm is used with the SUMS analytic model logic to calculate inferred orifice pressure values from inflight measurements of ion current. This section describes the major logic elements of the computer routines and the logical process for performing the calculations.

Figure 4 shows the expected variation of mass 28 ion current measurements to be obtained in flight with the SUMS instrument. This represents the raw flight data after conversion of the digitally encoded range and signal level values to actual ion current valves. The time interval shown is between the time at which HIRAP begins to provide useable data and the time at which the SUMS inlet valve closes. The sharp drop in the middle is the point at which the range valve closes. The dashed line at this point depicts the theoretical system response to range valve closure for an infinite pumping speed and no surface desorption. In this case the measurements immediately after range valve closure would be useable for data reduction since they would represent only the contribution of the atmospheric gas. However, because of the source pumping speed (15 cc/sec) and some N_2 desorption from surfaces, the actual signal will follow the solid line. For several scans the signal contribution of the residual gas in the source is a significant percentage of the total signal so that even small errors in modeling the decay characteristic of the system cause large errors in the reduced data. This effect is seen more clearly in Figure 5 where the ion current has been adjusted after range valve closure to account for the increased pressure drop after that time. This figure depicts the ion current that would result if the small leak were left on and the analyzer were capable of measuring the higher currents, except that the large spike would not occur. This spike is due to the aforementioned finite pump down which requires about 30 to 40 seconds to complete after the range valve is closed.

The first step in the inlet reduction process is the generation of a "static" orifice pressure profile. If the flight measurements of ion currents are assumed to have been made at static orifice pressure conditions, the inferred orifice pressure is calculated by the simple relationship

$$P_{OR(STATIC)} = \frac{I_{28}}{S_{28}}$$

to which the inlet reduction algorithm reduces for static conditions. Applying this relationship to the curve of Figure 4 produces the curve shown on Figure 6. The sharp spike following range valve closure occurs because the static assumption does not account for the contribution to signal of the background gas in the ion source during the pump down after range valve closure.

The "static" orifice pressure profile produces pressure magnitudes within five to thirty percent of actual orifice pressure valves and slopes within two percent of actual except during the leak switch transient. The transient problem is handled by deleting data over the transient interval and treating the data set in two segments referred to as range valve open (RVO) and range valve closed (RCV), the two segments lying before and after the transient, respectively. Each of the two segments are fitted with a polynomial to smooth the measurement "noise" which is expected to be about 3% maximum.

Simulation of SUMS response to the static P_{OR} profiles generates arrays of values for A, B, M and P_N at each five second interval over the data spans. These values are then used with I_{28} and S_{28} in the complete reduction equation to calculate valves of P_{OR} which include the effects of dynamic lag and natural response of the system. Figure 7 shows the typical differences between the actual P_{OR} and the reduced values determined by the process as just described.

Figure 8 depicts the major logic of the inlet reduction process with the additional steps required to complete the process for all atmospheric constituents. The final reduced values of $P_{OR,28}$ are combined with the static $P_{OR,28}$ table to calculate the fraction of static pressure for mass 28. This fraction is assumed to hold true for all species and is used to calculate the partial orifice pressure, $P_{OR,i}$ for each of the species by the relationship

$$P_{OR,i} = \frac{I_i}{R_{28}\ S_{28}\ F(s)}$$

where $P_{OR,n}$ = partial orifice pressure for the i^{th} specie, torr

R_{28} = fraction of static pressure for mass 28

S_{28} = mass 28 sensitivity, amp/torr

$F(s)$ = $\sum_{n=o,5} C_{i,n} I_i^{\,n}$; polynomial for the fractional sensitivity of specie i with respect to S_{28}

I_i = flight measured ion current for i^{th} specie, amps

Finally, the total orifice pressure is computed as

$$P_{OR} = \Sigma\, P_{OR,i}$$

The actual species to be included in this step of the SUMS data reduction are determined in an earlier step which selects the specific peaks to be processed by subsequent routines. The criteria for selection will be determined during post flight analysis of the individual mass spectra for each scan. The computer file which inputs the ion current measurements to the inlet reduction routines will only contain data for the previously selected peaks.

The analysis of SUMS mass spectral plots to determine chemistry and contaminate effects will be an ongoing process after flight with considerable uncertainty as to when results will be available; consequently, the need exists for a quick-look capability for data reduction which produces a reasonable first-order estimate of the flight results. Provision has been made at the end of the inlet reduction process (see bottom-right of Figure 8) to test a flag for quick-look processing and, if this flag is true, a quick-look algorithm is applied to the mass 28 partial pressures to produce a total pressure estimate. This algorithm can accommodate any arbitrary function for total pressure related to nitrogen partial pressure as determined from atmosphere models. The altitude vs. time history for use in this algorithm can be either the preflight prediction or Best Estimated Trajectory (BET) when available.

2.3 Data Management

The very large quantities of data obtained from one flight of SUMS and the plans for multiple flights requires attention to the problem of data management. The data management plan developed for SUMS is intended to minimize the number and volume of data files while simultaneously maintaining desired flexibility during the data reduction process and minimizing the recovery effort required in the event of a file media failure.

The critical SUMS data file is the science and engineering data file. After this file is successfully stored on the HP hard disc and archived 3.5 floppy disc copies are made, all preceeding tapes and files in the process are released except the OEX-CCT which is retained indefinitely. (This tape is also archived at the OEX data laboratory at NASA/JSC.) The PEAKS files are saved and archived.

The SUM_POOL_n file is created on the hard disc for each flight and will be maintained indefinitely. This file contains the entire pool of data needed for analysis of the SUMS data. It can be updated when new data becomes available from the various data sources or when required during analysis. The file can also be checkpointed at any time and archived at any given state for future reference. All files which input to the POOL file can be released after the initial archiving.

SECTION 3 - SUMS CALIBRATION

This section describes the calibration tests conducted with the SUMS flight hardware prior to the first SUMS flight on the STS-32 mission. The data obtained from these tests was used to determine the static sensitivity of the instrument to an external gas sample in terms of amperes of ion current per unit orifice pressure and to determine the calibration constants for the inlet reduction algorithm used for flight data reduction. The results of these tests are valid for the configuration as tested. Future SUMS flights will be conducted with a different configuration due to the "chin panel" modification being performed on OV-102 and, therefore, the dynamic response will be changed, requiring recalibration.

3.1 Static Calibration

Static calibration of SUMS was performed by exposing the inlet to various static pressures over the instrument operating range and plotting the results in terms of ion current versus orifice pressure. The slope of this curve is the "sensitivity", S, of the instrument, and proved to be nearly constant for SUMS after adjustment of the ion pump high voltage from 3500 to 1800 volts. The measured sensitivity for range valve open was 1.79×10^{-7} amperes per torr and for range valve closed was 1.43×10^{-9} amperes per torr.

3.2 Dynamic Calibration

The closed-source configuration of the SUMS system results in a significant pressure lag in the presence of an increasing orifice pressure which will occur during reentry. This dynamic lag is expected to produce ion current measurements which are consistent with equivalent static orifice pressures up to 30% less than the actual inflight orifice pressures. The dynamic lag is taken into account in the inlet reduction step in the SUMS flight data reduction process. The inlet reduction software employs the SUMS analytic model which, due to simplifying assumptions and approximations, must be calibrated against the actual system response to an increasing orifice pressure.

3.2.1 Dynamic Test Pressure Profile

The predicted inflight orifice pressure history is

$$P_{OR} = P_o e^{K(t)t}$$

where K(t) varies to first order with the inverse of atmospheric scale height. Such a pressure-time history is difficult and costly to simulate in the laboratory and it is not the most severe test of the analytic model.

A simple and easy to implement test pressure profile is of the form

$$P_{OR} = P_f \left(1 - e^{-Kt}\right) + P_o$$

where P_f is some final pressure to which the orifice pressure rises exponentially from an initial pressure of P_o. This rise is characteristic of a volume at high pressure pumping into a reference volume initially at high vacuum through a small orifice. The parameter K is determined by the magnitude of the reference volume and the conductance of the orifice.

If K is very small (very long time constant), the pressure rise in the reference volume will be nearly linear over a considerable period of time from the start. A linear pressure rise offers the interesting possibility of checking repeatability during the dynamic tests because the dynamic response is independent of the pressure rate for a linear rise. The equation for fraction of static pressure in 2.2.1 can be written to first order for a linear rise as

$$R = 1 + \frac{B}{A}\frac{\dot{P}_{OR}}{P_{OR}} = 1 + \frac{B}{A}\ \frac{k}{P_o + Kt}$$

which, for $P_o \to o$, reduces to

$$R = 1 + \frac{B}{At}$$

A linear pressure rise from an initial high vacuum also offers the advantage of checking the analytic model over a greater range of dynamic response than will occur in flight. The fraction of static pressure starts at zero and rises at a rate dependent upon the ratio B/A, eventually converging on 1.0 at large t.

Figure 9 shows the fraction of static pressure versus time as predicted by the SUMS analytic model for pressure rise rates of 1×10^{-5} torr/second with range valve open and 1×10^{-3} torr/second with range valve closed. Any rates would have produced the same curves. The small difference between the cases for the two range valve positions is caused by a slight change in the ratio B/A when switching leak conductances.

3.2.2 Test Procedure

Figure 10 depicts the test hardware configuration for the dynamic calibration tests. The SUMS orifice tube was connected directly to the test station "cross" which has a volume of about 1/2 liter. Nitrogen at one atmosphere was supplied through a controlled leak with a tap to the cross. The vacuum station was connected to the cross through a manual valve. This valve was initially opened full at the beginning of a test. The controlled leak was adjusted to give a pressure of 1×10^{-6} torr at the reference volume. The valve was then closed (time equal zero), starting the test run. The subsequent pressure rise in the reference volume would be nearly linear as discussed in the previous paragraph. Baratron pressure at the cross and mass 28 peak ion currents from the SUMS were recorded on strip charts as the run progressed. Subsequent runs at higher pressure rates were obtained by simply increasing the initial pressure through an increase in the conductance of the controlled leak. Doubling the initial pressure doubles the pressure rate.

3.2.3 Test Cases

A total of six dynamic tests were performed. Five of the tests were run with the range valve initially open while the sixth was run with the range valve manually closed at the start. Case 1 was run a few weeks prior to the other tests and used approximately the same pressure rate as Case 3. The cases are tabled as follows:

Case #	Range Valve Position	Initial Pressure Rate
1	open	2.89×10^{-5}
2	"	1.45×10^{-5}
3	"	2.75×10^{-5}
4	"	4.12×10^{-5}
5	"	9.19×10^{-5}
6	closed	1.65×10^{-4}

The pressure profiles for the tests are shown on Figure 11.

3.2.4 Test Results

Figure 12 shows the variation with time of the AMU 28 peak ion current recorded for each of the six test cases. The data are corrected for initial static background current measured prior to time zero for each case. The dynamic lag in the system response is clearly seen on Figures 13 and 14 which show the effective "dynamic sensitivity" compared with the static sensitivities for range valve open and closed cases, respectively.

Figure 15 shows a typical dynamic calibration test (case 3) result compared with the calibrated model prediction. The only adjustment that was made to the model was to element C_2 which is the lumped volume just ahead of the leaks. C_2 was set to 8.0 cc based on best fit to the calibration data. Other test cases agree with the calibrated model as well as case 3 except for test case 5. Exhaustive analysis of this case and the test technique failed to explain the discrepancy. Future recalibration tests prior to the resumption of STS operations should reveal whether a problem exists with the higher pressure rates or whether the case 5 result was anomalous.

SECTION 4 - SUPPORTING ANALYSES

This section presents the status and future plans for several ongoing analyses which are being conducted in support of the SUMS experiment.

4.1 Flow Field Algorithm

An analysis of the flow field about the Shuttle Orbiter nose geometry in rarified hypersonic conditions is being conducted in support of development of the SUMS flow field algorithm which will relate measured orifice pressures to dynamic pressure. Partial results of this analysis were published in Reference 4. Although not a part of this contract, this analysis effort has been coordinated with respect to SUMS needs with respect to flight data reduction and interpretation.

The flow field analysis to date has provided nominal values of pressure coefficients at several altitudes over the SUMS measurement range. These coefficients relate the measured orifice pressures from SUMS flight data to dynamic pressure which is needed for calculation of aerodynamic coefficients. The values received to date have been curve fit and the resulting polynomial coefficients and logic have been incorporated into the SUMSAERO program.

Future work in this area will include expansion of the nominal analysis and the generation of error coefficients for estimation of uncertainties in the overall SUMS analysis results.

4.2 HIRAP Derived Density Variations

Inferred free stream atmospheric densities calculated from the HIRAP normal acceleration measurements indicate the possibility of rather large spatial fluctuations in density relative to standard. This poses the possibility of large gradients in SUMS orifice pressure which may affect the SUMS system response and present a problem with reduction of flight data to orifice pressure values. The previous discussion in Section 2 of the inlet reduction process assumed that the orifice pressure increases as a smooth exponential and accuracies quoted for the process were based on that assumption. The HIRAP results indicate large, up to ± 30%, periodic variations, which, if due to atmosphere, could be problematical.

This problem was initially investigated by modeling the HIRAP inferred variation as a sine wave with period as observed and amplitude of ± 30 percent of the standard atmosphere. The model was used to develop an orifice pressure profile based on the flow field algorithm relating dynamic pressure (density) to orifice pressure. The orifice pressure profile was used to drive the SUMS analytic model which calculated the AMU 28 ion current including the effect of dynamic response. The resultant AMU 28 ion current values were then input to the inlet reduction software to recreate the original orifice pressure profile. After some changes to the inlet reduction process (resulting in the current version), the errors in the reduction process were of the order of one percent maximum.

Data for the ten HIRAP flights to date have been transferred from NOS tapes to the HP 9836 system. These files contain time trajectory and altitude parameters, normal and axial accelerations, control surface deflections, and the atmospheric densities calculated from normal acceleration and normal force coefficient. The MSIS-83 (reference 5), MSFC/J70 (reference 6), and the 1976 U.S. Standard Atmosphere (reference 7) models were programmed in BASIC on the HP system and checked out thoroughly against their respective FORTRAN versions on the CDC system. Three sets of data files (one for each atmosphere model) were then generated with data from the HIRAP files combined with model density, the ratio of HIRAP density to model density, exospheric temperature, local temperature, local solar time, solar flux, and geomagnetic index, A_p. A program was then written to plot the various parameters from these files.

The density ratios for all ten cases were plotted and analyzed. The altitude range for the data is from 60 to 160 km. Below 80 km, the models tend to overpredict compared to the HIRAP valves. From 80 to 120 km, a wavelike structure with amplitudes of ± 20 percent variation frequently occurs. From 120 km to 160 km, the general model trend is underprediction of density. These overall trends hold up well when the ten data sets are averaged, except that the oscillations in the mid range are diminished because of randomness.

The STS-32 case is particularly interesting because of a very large gradient in the density ratio around 107 km. Accepting this gradient as a variation in atmospheric density is difficult because of the sharp change in inferred scale height by a factor of two over a very small altitude change, three km. Even the lateral distance involved is very small, less than 150 km. The lift to drag ratio, L/D, could be an indicator of any cause which would produce the results of STS-32 because L/D is independent of atmospheric density except for the long term variation with Knudsen number (related to density). If the L/D history shows any unusual behavior around 107 km, a flow field effect or an impulsive force becomes suspect. L/D histories for all ten HIRAP flights were calculated with correction to a forty degree angle of attack. The STS-32 case shows a definite feature, a "bump", in L/D around 105 km where the largest gradient in inferred density occurs. Similar features are observed in six other cases in the range of 102 to 108 km with the magnitude of the effect varying from slight to even more pronounced than on STS-32. The other three cases do not show any obvious deviation from a smooth curve through that region.

Averaging all ten L/D histories produces a curve which is very smooth, almost linear, through the region 100 to 110 km as the flow transitions from free molecule to continuum. Since the features in the individual curves average out over the ten cases and since they do not even occur in three cases, one may conclude that either they are random and unrelated or that they are influenced by one or more variables. The theoretical L/D is related to Knudsen number through density and therefore indirectly to altitude. Density variations of ± 40 percent in the altitude range 100 to 110 km could be expected from flight to flight; therefore, the altitude range for a given Knudsen number would be about ± 3 km, assuming a scale height of 6.5 km (U.S. Standard at 105 km). If the features are commonly related to physics of the flow field as influenced by Knudsen number, they would then be confined to that altitude range, they should exhibit similar characteristics, and they should occur on every flight. Although the features do fall within the altitude range, they differ qualitatively (ie., some concave, some convex) and they do not appear in all cases.

Analysis of the angle of attack and attitude thruster firing histories led to the idea that analysis of the ACIP rate gyro data might provide further insight into the HIRAP results. The resultant data reduction and analysis that ensued is discussed in 4.3.

4.3 ACIP Rate Gyro Data Analysis

Software programs have been developed to strip the ACIP rate gyro data from the OEX-CCT tapes and transfer the data from the CDC system to the HP 9836 system via 9-track magnetic tapes. Analysis programs have been developed to smooth the angular velocity (p, q, r) data and calculate angular accelerations. The angular accelerations are used to calculate total moment about the orbiter body axes which facilitates calculation of the moment coefficients. The moment coefficient of interest in particular is the pitching moment coefficient.

Rate gyro data for STS-32, 30 and 24 have been reduced to date. Analysis of this data showed a near constant moment about the y body axis on the orbiters of about 250 ft lb prior to the buildup of aerodynamic forces during reentry. This moment swamps the aerodynamic moment during descent to about 120 km. The majority of the moment is caused by the APU exhaust which is directed upward at the aft body. Detailed analysis of the STS-24 data during the interval around APU-2 and 3 turn on shows an increase in angular acceleration to 2.05×10^{-3} deg/sec^2 as these units come on line. The value just before their turn on was 9.02×10^{-4} deg/sec^2, resulting in a difference of 1.15×10^{-3}. This difference is two thirds of the total APU induced moment, for a total of 1.72×10^{-3} deg/sec^2 for all three APU's. This compares with a calculated value of 1.95×10^{-3} based on thrust and moment arm.

The residual moment in the STS-24 data after subtracting the calculated effect of all three APU's is about 40 ft lb. This residue increases linearly to 58 ft lb at entry interface. Part of this "residue" could be due to variations in APU exhaust thrust magnitude (the calculation in the previous paragraph implied equal thrusts) and the long term increase could be due to increase in gravity gradient torque during descent. Further study of this problem will be done to develop as accurate a technique for removing the bias as possible.

The rate gyro/pitching moment analysis is only partially complete at this time but will be continued during a future contract. The analysis should aid the overall HIRAP density analysis effort and will be a valuable addition to the SUMS-HIRAP analysis for future flights. The software developed for this analysis will be incorporated into the SUMS Flight Data Reduction and Analysis System.

SECTION 5 - REFERENCES

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2. Hinson, Edwin W., "SUMS Preliminary Design and Data Analysis Development", NASA CR-165696, May 1981.

3. Dushman, Saul, "Scientific Foundations of Vacuum Technique", 2nd Edition, John Wiley and Sons, N.Y., 1962.

4. Moss, J. N. and Bird, G. A., "Monte Carlo Simulations in Support of the Shuttle Upper Atmospheric Mass Spectrometer Experiment", AIAA Paper 85-0968, June, 1985.

5. Hedin, A. E., "A Revised Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data: MSIS-83", JGR, Vol. 88, p. 10170, 1983.

6. Johnson, Dale L. and Smith, Robert E., "The MSFC/J70 Orbital Atmosphere Model and the Data Bases for the MSFC Solar Activity Prediction Technique", NASA TM-86522, November, 1985.

7. "U.S. Standard Atmosphere, 1976", U.S. Government Printing Office, October, 1976.

SECTION 6 - LIST OF FIGURES

FIG. 1 SUMS FLIGHT DATA PROCESSING FLOW, MAINFRAME SEGMENT

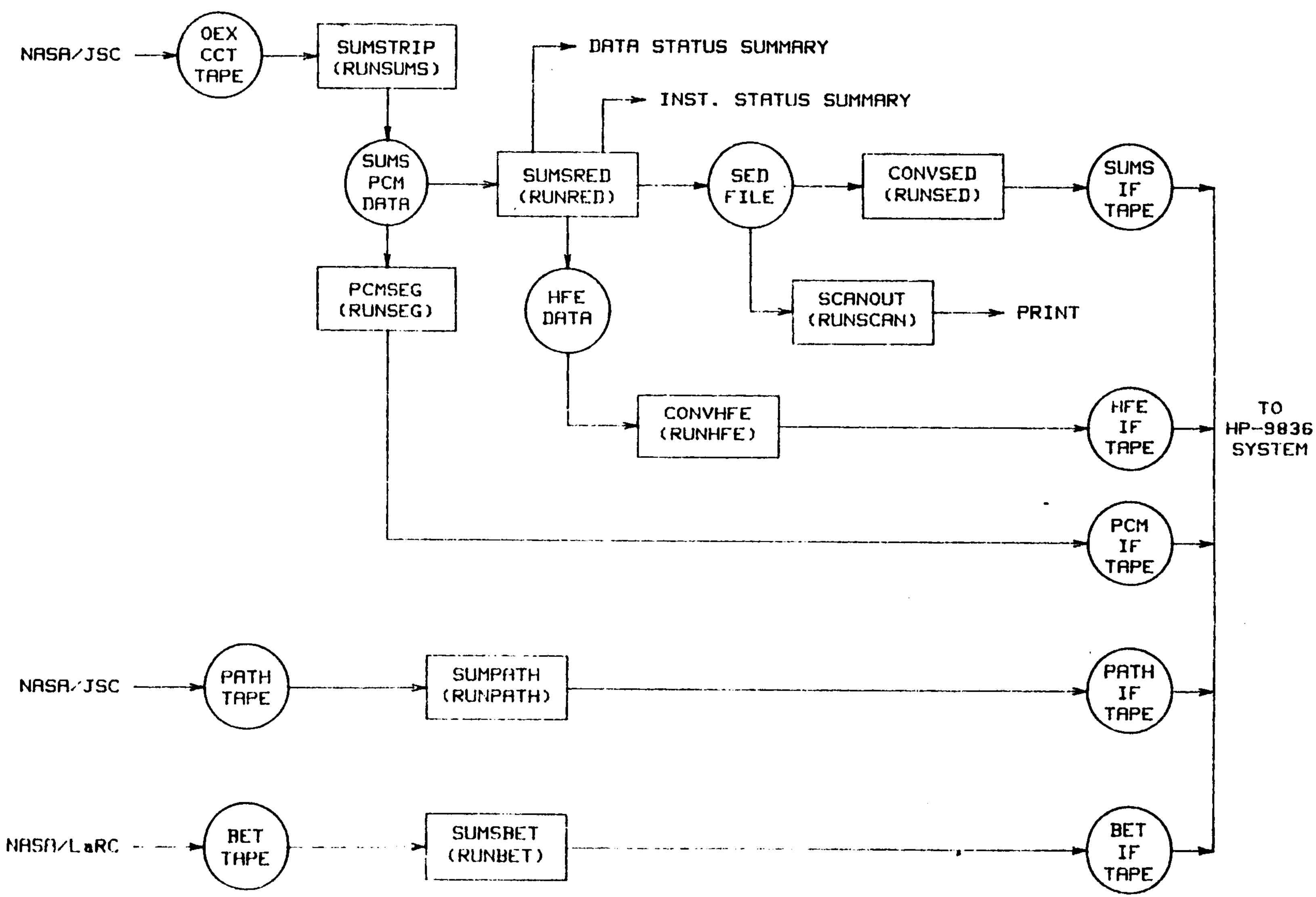


FIG. 2 SUMS FLIGHT DATA PROCESSING FLOW
HP-9836 SEGMENT, PART 1 OF 2

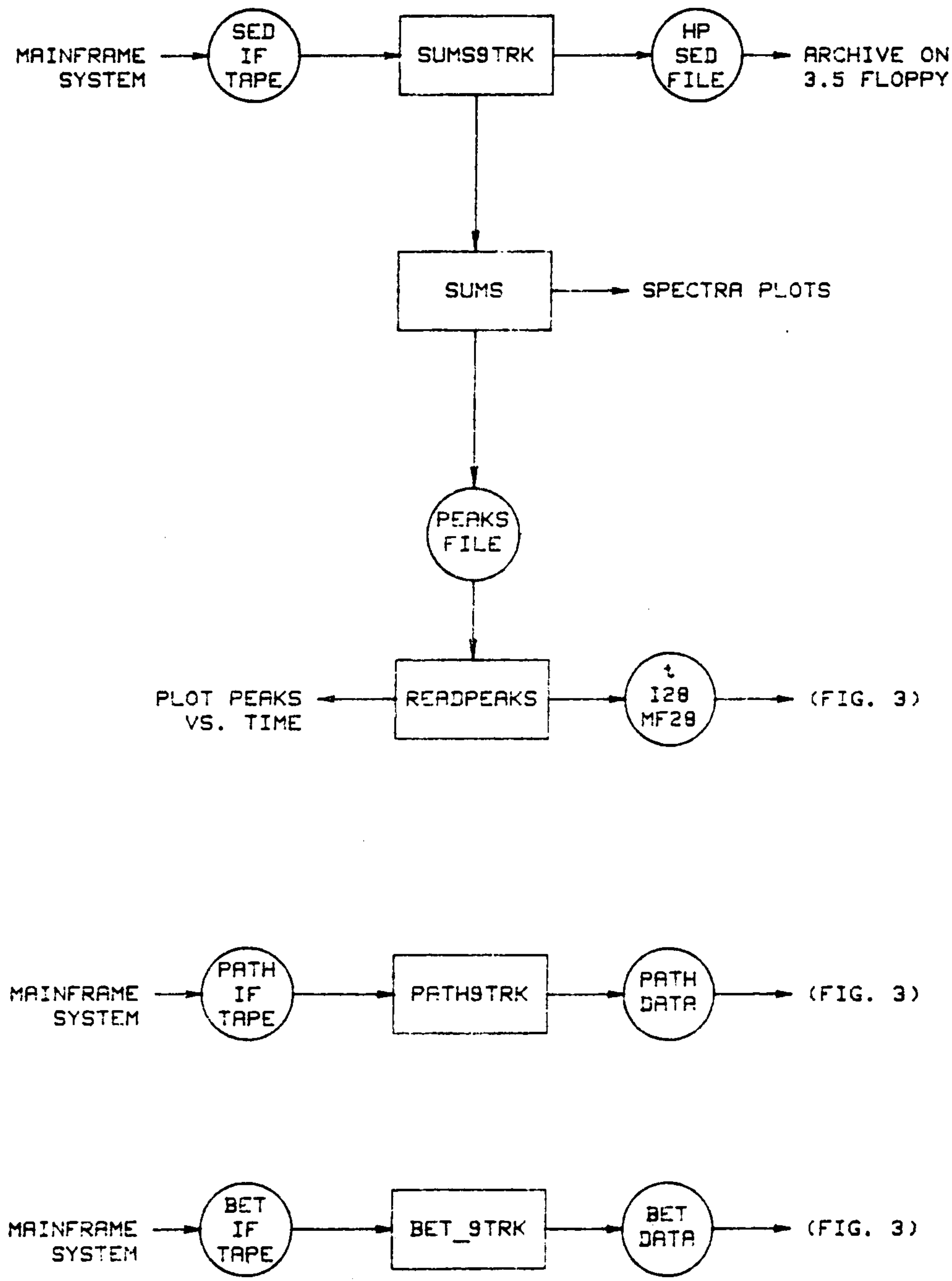


FIG. 3 SUMS FLIGHT DATA PROCESSING FLOW
HP-9836 SEGMENT, PART 2 OF 2

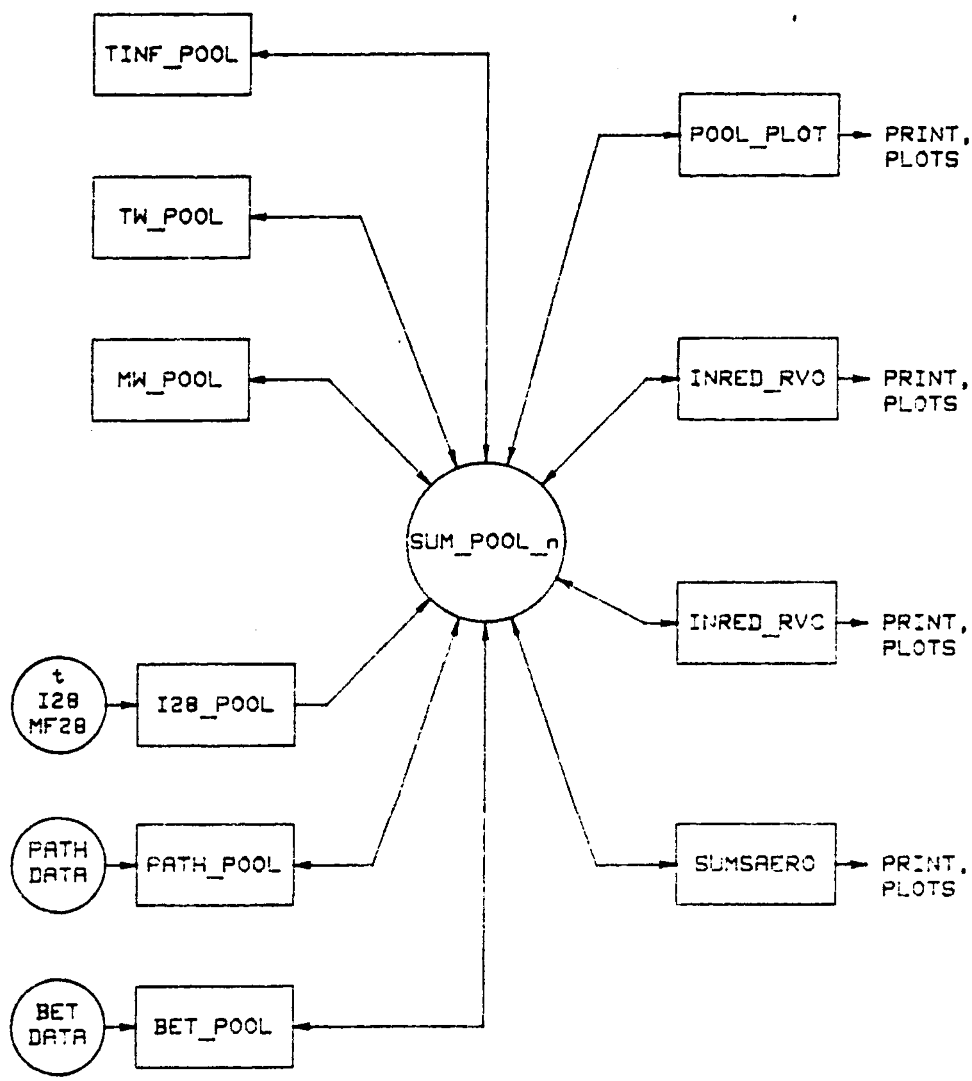


FIGURE 4 PREDICTED AMU 28 ION CURRENT

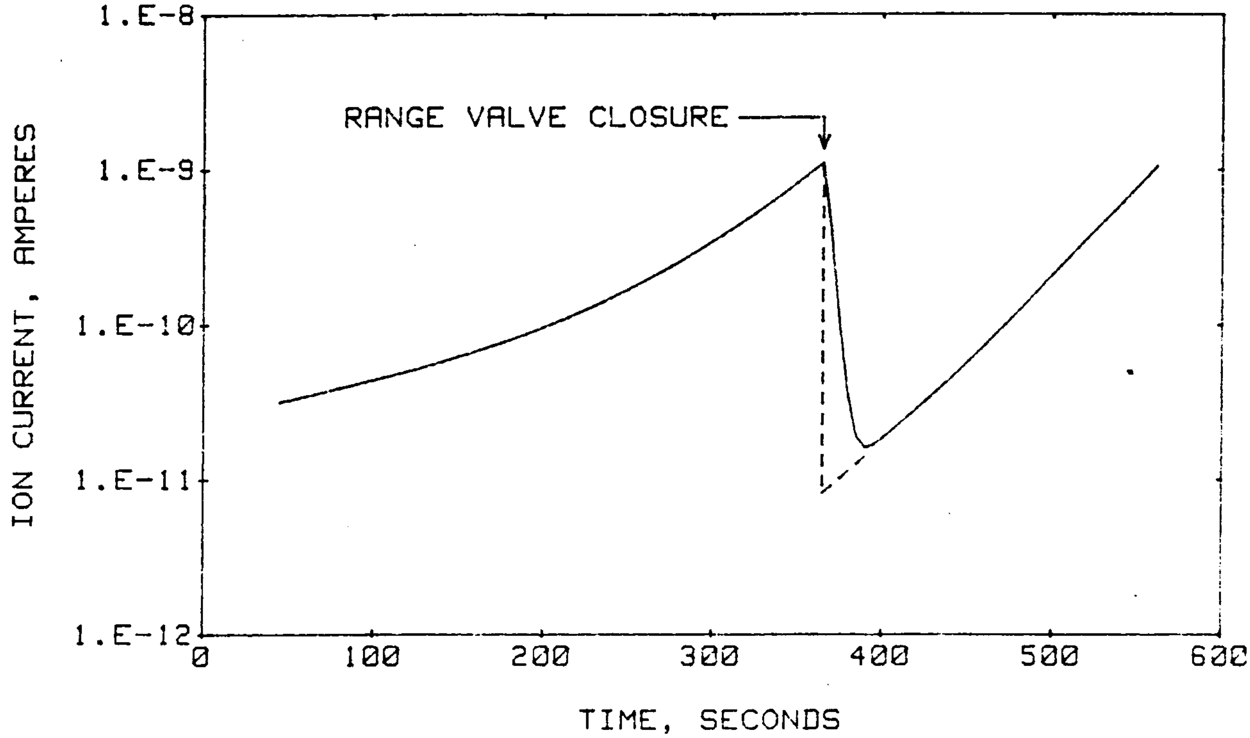


FIG. 5 RELATIVE I28 CORRECTED FOR DYN. RANGE

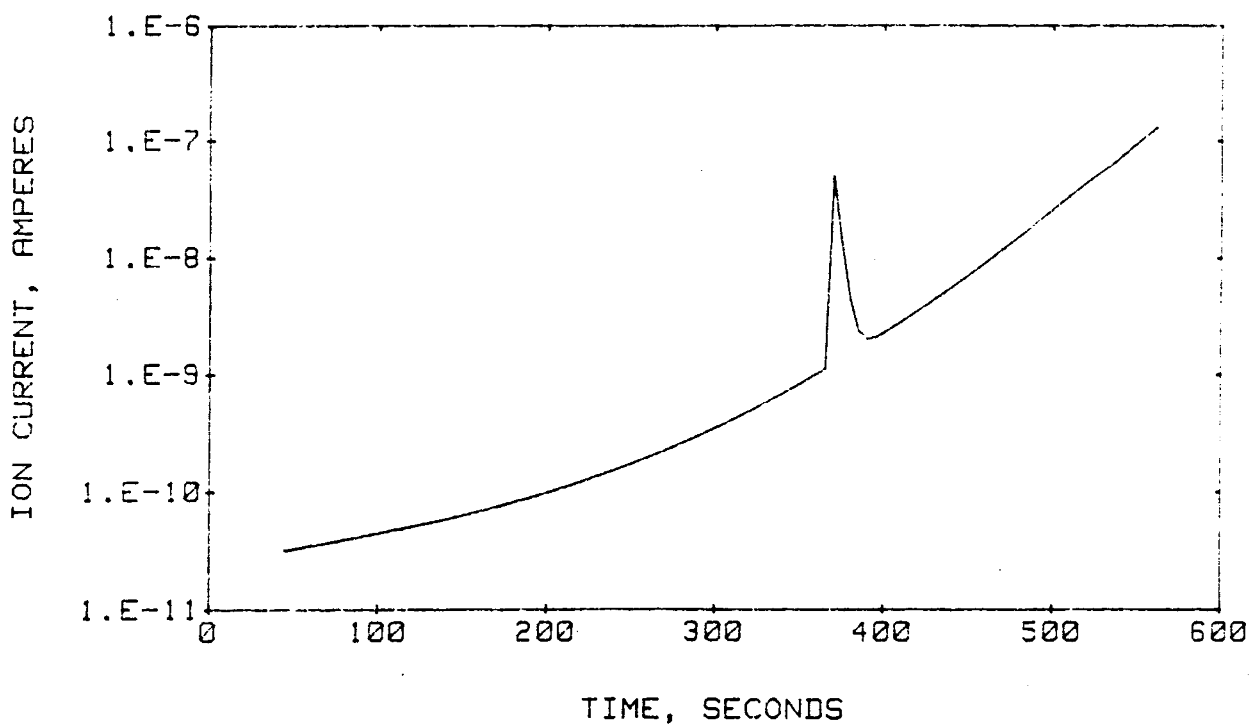


FIG. 6 STATIC APPROXIMATION TO Por HISTORY

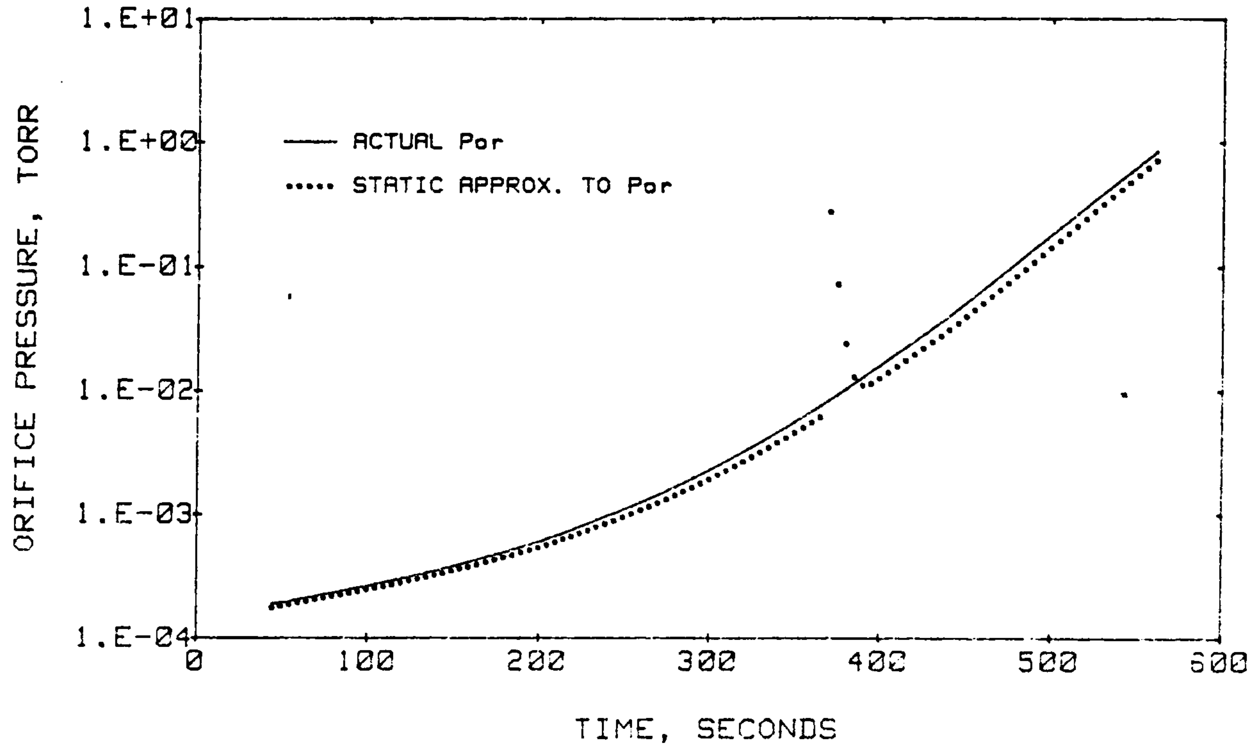


FIG. 7 ERROR BETWEEN REDUCED AND ACTUAL Por

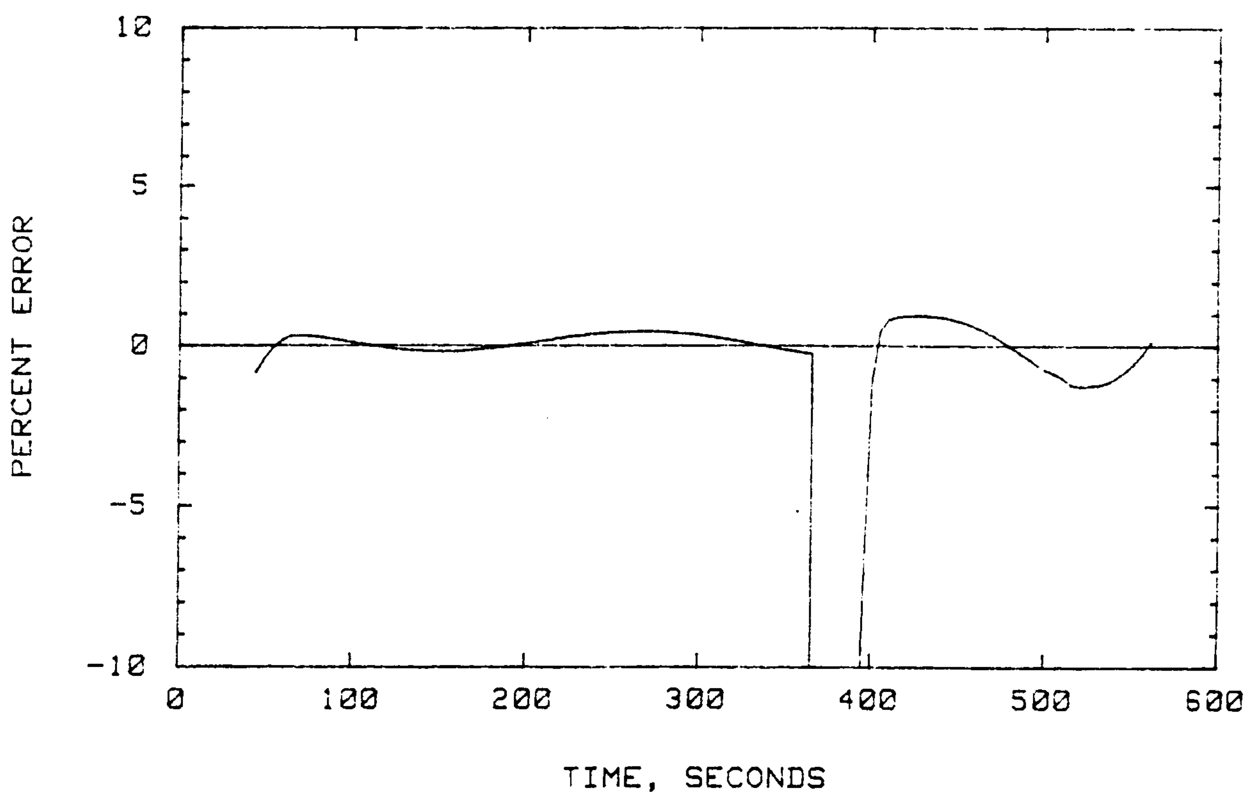


FIG. 8 INLET REDUCTION LOGIC

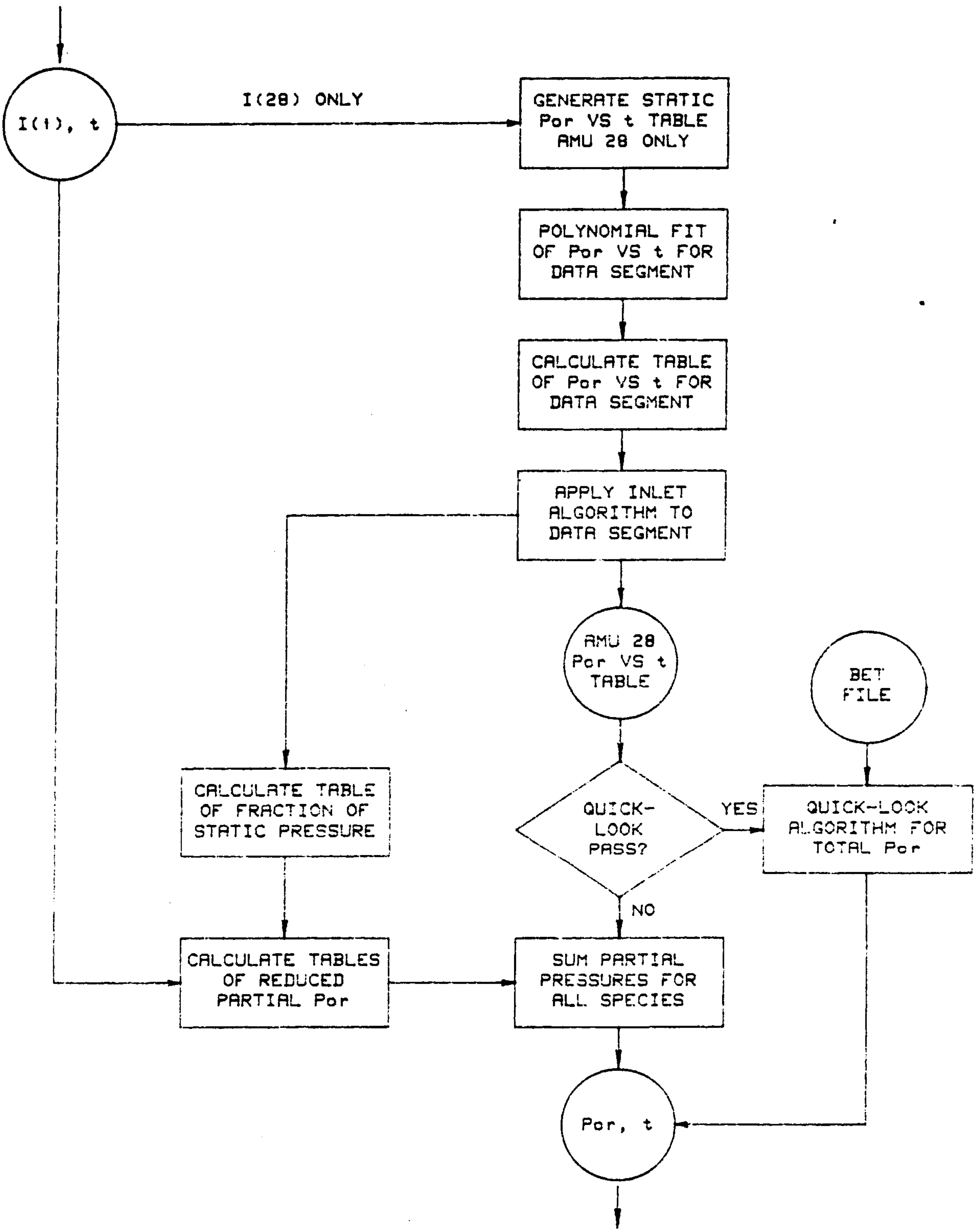
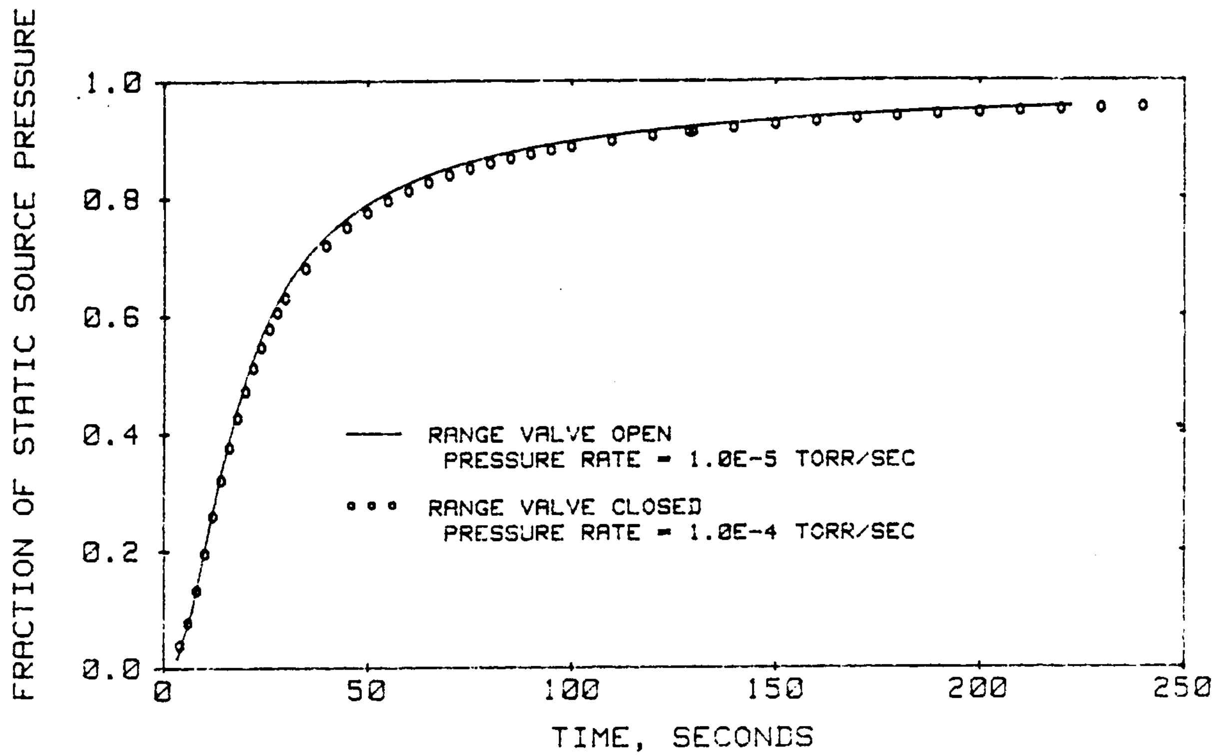


FIG. 9 TYPICAL PREDICTED DYNAMIC TEST RESPONSE



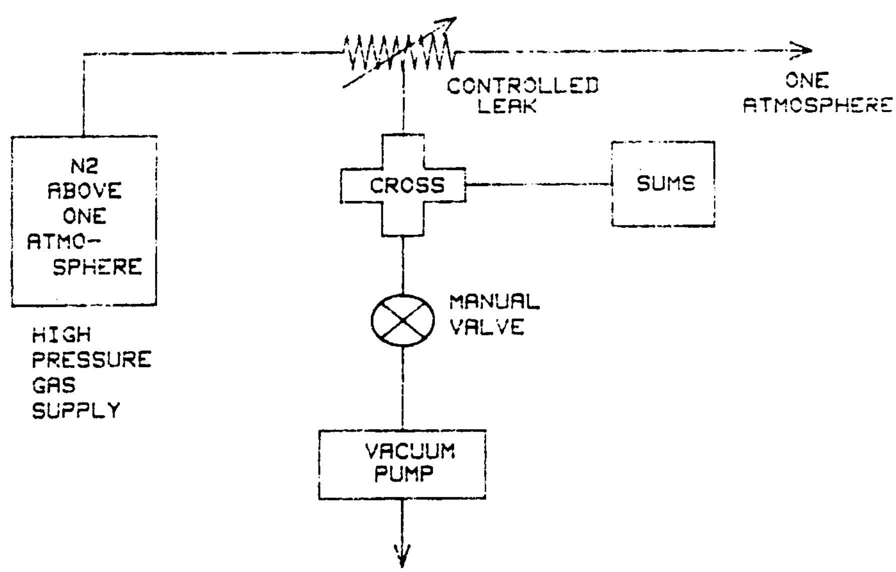


FIG. 10 DYNAMIC CALIBRATION TEST CONFIGURATION

FIG. 11 DYN. CAL. TEST ORIFICE PRESSURES

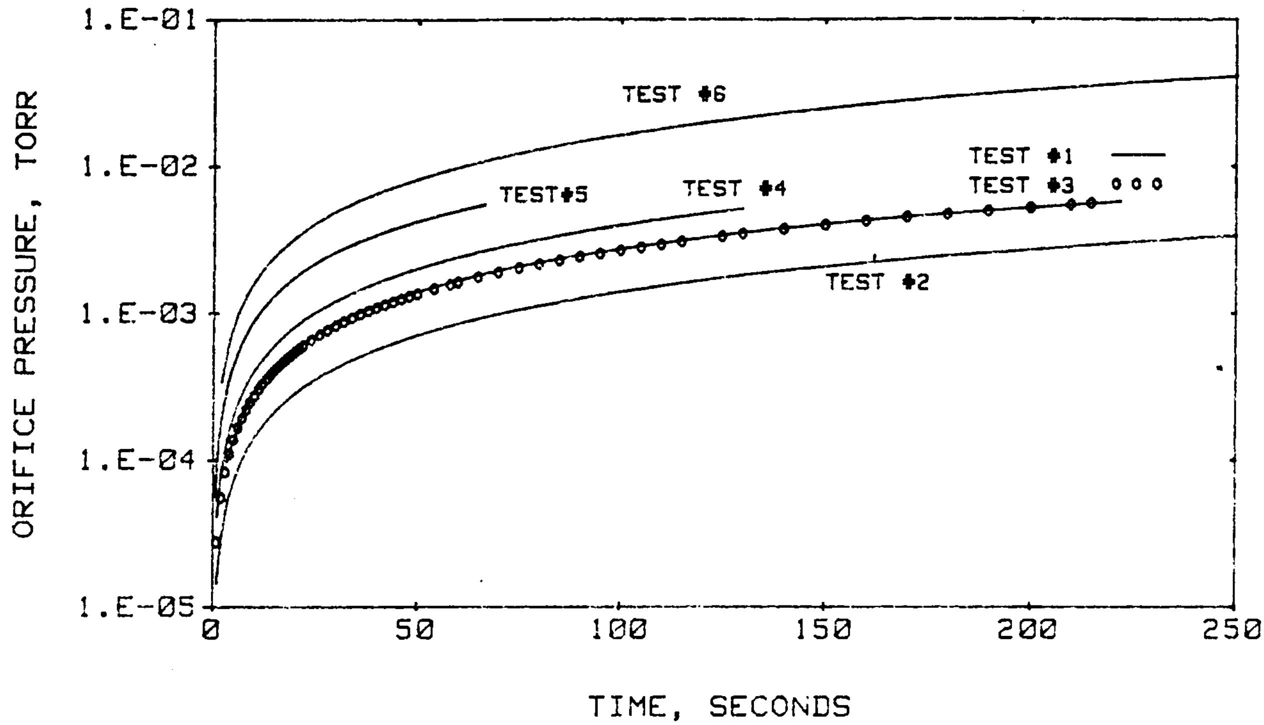


FIG. 12 DYN. CAL. TEST ION CURRENTS

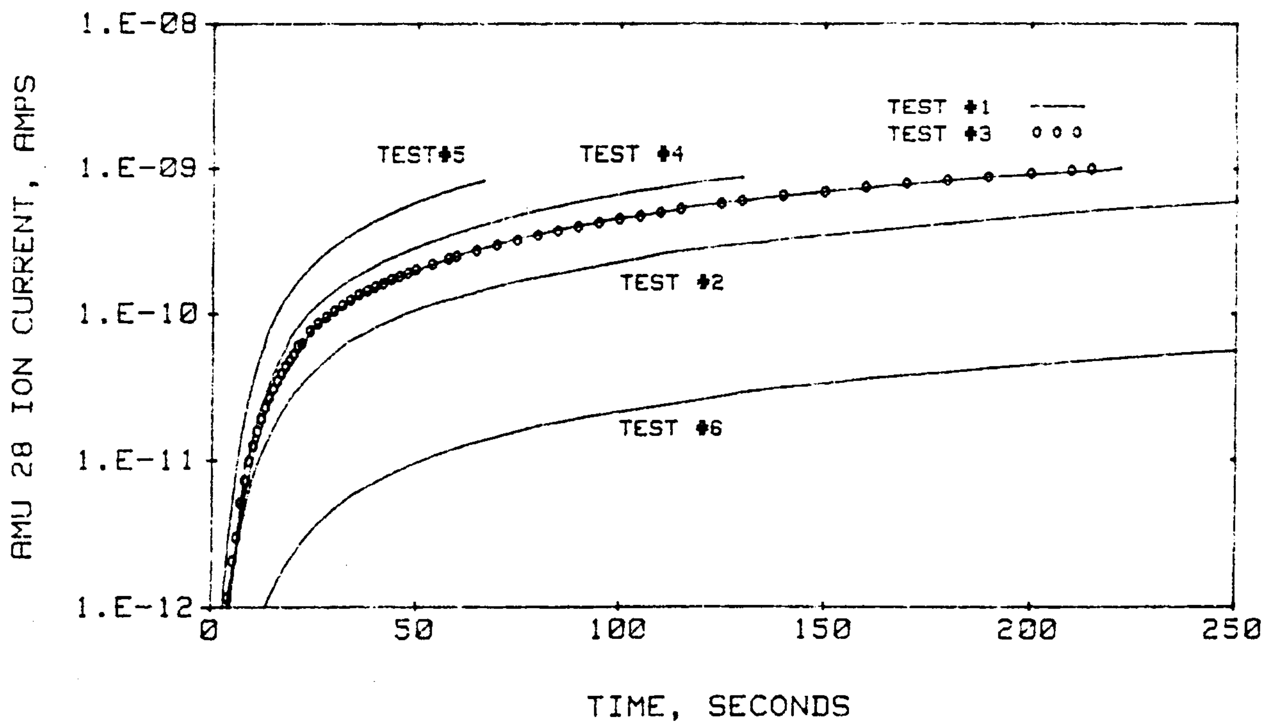


FIG. 13 TYPICAL DYNAMIC SENSITIVITY
RANGE VALVE OPEN

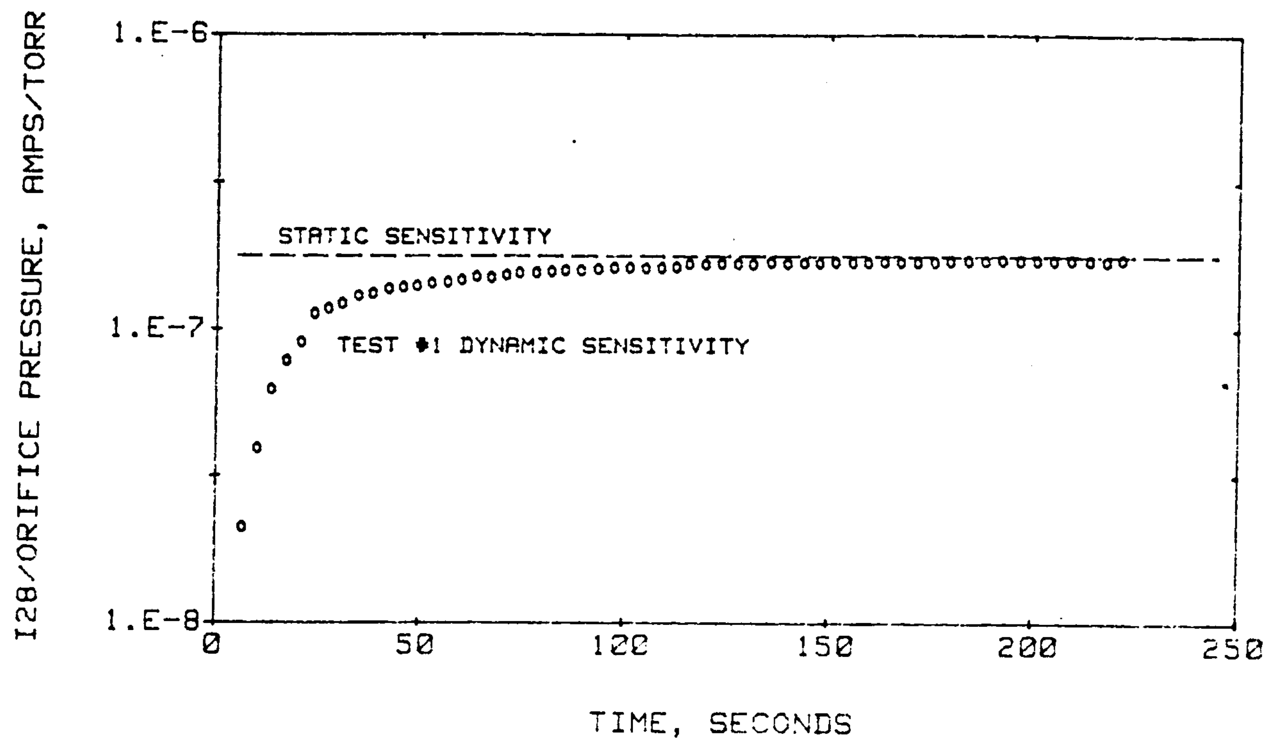


FIG. 14 TYPICAL DYNAMIC SENSITIVITY
RANGE VALVE CLOSED

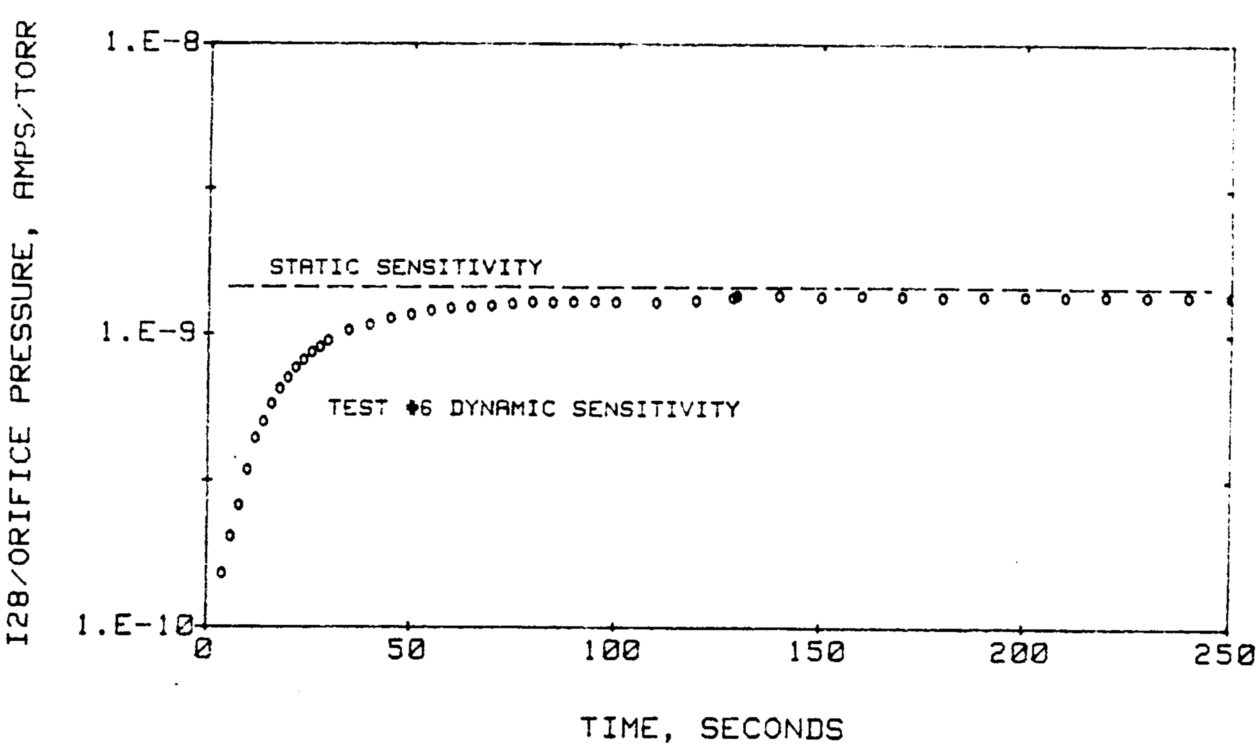
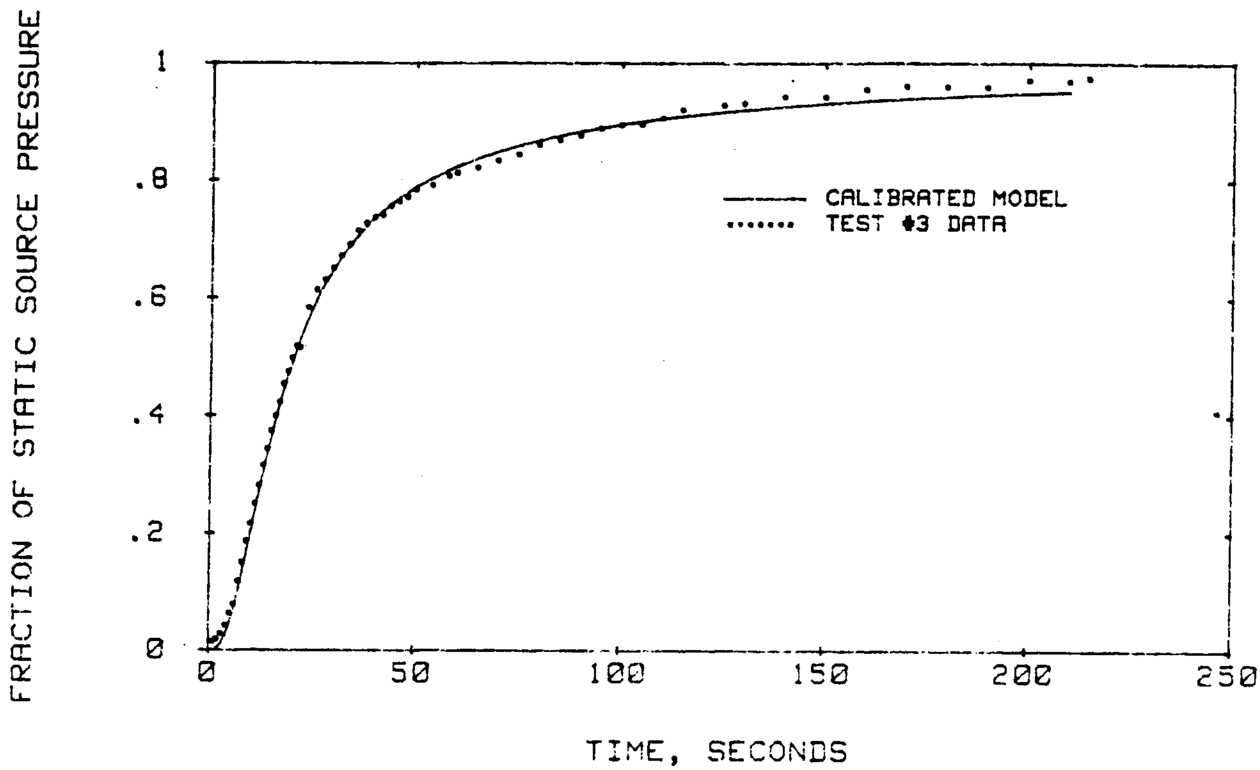


FIG. 15 TYPICAL COMPARISON OF DYN. TEST
WITH CALIBRATED MODEL



ATTACHMENT A

INTERIM REPORT

Interim Report

Results of Shuttle Upper Atmosphere Mass Spectrometer (SUMS) 61-C Flight Data Analysis

Edwin Hinson

NAS1-16385

May 1986

Table of Contents

1.0 Introduction

The Shuttle Upper Atmosphere Mass Spectrometer (SUMS) installed on Shuttle Orbiter OV-102 (Columbia) was flown for the first time on Shuttle Flight 61-C in January, 1986. Columbia was launched on January 12, 1986, at Kennedy Space Center and landed at Edwards AFB, Cal., on January 18, 1986. This was Columbia's first flight after extensive modification which included the installation of SUMS and other major Orbiter Experiments Project (OEX) flight hardware.

The major objective for SUMS on this first flight was to demonstrate its operational status and to collect data on gas composition and density at the SUMS inlet port during reentry. This data would allow assessment of the SUMS inlet system design parameters and would facilitate the determination of hypersonic, rarified flow aerodynamic coefficients in the transition regime in conjunction with the High Resolution Accelerometer Package (HIRAP). A secondary objective was to evaluate the on-orbit performance of the SUMS system and the procedures for making SUMS/HIRAP measurements of atmospheric density and accelerations during orbital operations. For this purpose, a series of three orbital sequences were executed during the mission.

SUMS flight data was recorded on the OPS-1 recorder during the orbital sequences and the early segment of reentry up to entry interface minus 50 seconds. Reentry data from entry interface minus 105 seconds to landing was recorded on the OEX recorder. The OPS-1 sequences in orbit were dumped to the Hawaii ground station on a telemetry channel and processed via JSC to LaRC using the OEX ground data system. The reentry segments on the OPS-1 and OEX recorders were processed through the OEX data system after return of Columbia to KSC. All SUMS flight data was successfully processed through the SUMS flight data reduction system at LaRC with no problems. Mass spectra plots were available on the HP 9836 system typically within 24 hours of data receipt at LaRC.

Analysis of data from the three orbital sequences showed apparently normal instrument operation but no evidence of atmospheric or contaminant gases other than preflight background levels in the mass spectra. Engineering parameters were all within specification and all valves were commanded open. The reentry data also showed normal instrument operation and all valves commanded open but also no evidence of atmospheric or contaminant gases. The expected valve closures failed to occur at the predicted times and no rises in the atmospheric gas peaks were observed. The contingency command to close all valves was issued by the SUMS sequence and control logic when the inlet pressure transducer reached the maximum of 5.4 torr at low altitude. These flight data results indicated a possible valve malfunction or clogged filter which prevented atmospheric gas from reaching the mass spectrometer through the inlet system.

SUMS was removed from Columbia at KSC and ground tests were conducted to determine the reason for the apparent in-flight malfunction. The tests at KSC provided preliminary indication that the protection valve had failed closed. SUMS was then transported to the University of Texas at Dallas (UTD) where further tests confirmed erratic operation of the protection valve.

2.0 SUMS 61-C Orbital Operations

SUMS was designed to measure partial pressures of atmospheric gas constituents at the SUMS inlet port in the transition region between free molecular flow at orbital altitudes and continuum flow after reentry. Practical considerations dictated some tradeoff of measurement range at high altitudes. Yet measurement of atmospheric gases at orbital altitudes is possible given the right conditions of altitude and solar activity, the two major variables affecting density in the thermosphere. Successful measurement of atmospheric parameters with SUMS in conjunction with HIRAP acceleration measurements at orbital altitudes would greatly enhance knowledge of free-molecular flow aerodynamics of the Orbiter.

Mission 61-C was flown during the period of very low solar activity within the current 11 year sunspot cycle. The orbital altitude was also higher than initially planned because of lower payload weight. These factors virtually eliminated the possibility of making aerodynamically useful orbital measurements with SUMS and HIRAP on this mission. Figure 1 was generated with postflight values of observed 10.7 cm solar flux and shows that ion currents generated by atmospheric nitrogen and oxygen at the 61-C altitude would have been an order of magnitude below background levels and therefore undetectable.

The merit of performing the SUMS orbital sequences can certainly be questioned in light of such pessimistic predictions. The factors which entered into the decision to perform them anyway were the very light crew workload on mission 61-C making the Orbiter readily available for the required attitude maneuvers, the relatively unpredictable solar activity, and the potential secondary benefits such as contaminant and background measurements.

Figure 2 is of interest regarding future attempts to make orbital measurements with SUMS for aerodynamic purposes. This graph was generated for high solar activity which should prevail before the SUMS flights are completed due to the Shuttle program delay caused by the Challenger loss. Adequate atmospheric signal levels are indicated at 300 km and below.

2.1 Orbital Sequence Description

The SUMS flight operations on mission 61-C were specified by Detailed Test Objective (DTO) 0902, JSC-16725, Revision G. This DTO establishes the SUMS command history and orbiter attitude maneuvers required to perform the orbital sequences.

The baseline sequence contained in DTO 0902 is summarized briefly as follows: (1) SUMS and HIRAP power is applied 2 hours before the sequence for warmup, (2) the orbiter is maneuvered nose down, SUMS orifice forward at a pitch attitude of -110 degrees, (3) data recording is started, (4) the orbiter is pitched negatively at 0.5 deg/sec to rotate the orifice through the velocity vector up to an attitude of +90 degrees, and (5) the recorder is stopped and SUMS/HIRAP powered off. The Orbiter maneuver provides maximum projected area which creates maximum drag acceleration for HIRAP at the beginning and end of the sequence and also provides zero angle of attack of the SUMS port (maximum sensitivity to atmosphere) near the middle of the sequence. Probability of sensing the atmosphere is maximized by performing the sequence at local solar time equal to 1400 hours (the middle of the diurnal bulge).

Only one orbital sequence was implemented for SUMS during the preflight mission planning for 61-C. This sequence was originally scheduled for day 4 of a nominal 5 day mission. In flight, the mission was first shortened by one day and the SUMS sequences rescheduled for day 3. Subsequently, the mission was extended to 6 days because of KSC weather problems, allowing two additional SUMS orbital sequences during this period of very low Orbiter activity. The three SUMS orbital sequences are identified and labeled as ORB-1, ORB-2, and ORB-3.

2.2 Flight Data Results from Orbital Sequences

The target values for initial pitch attitude, pitch attitude rate, and final pitch attitude for the SUMS orbital sequences were -110 deg., 0.5 deg/sec, and +90 deg, respectively, while holding yaw and roll angles within the range of ±10 deg. Tolerances on pitch angles were ±5 deg. No tolerance was specified for pitch rate during the maneuver but values in the range of 0.4 to 2 degrees per second are considered acceptable. The actual attitude rates achieved during the mission were 0.83, 0.49, and 0.53 deg/sec for ORB-1, ORB-2, and ORB-3, respectively.

Figures 3, 4, and 5 show the angle of attack histories for the SUMS inlet port relative to the velocity vector for each of the orbital sequences. These figures are approximations which were constructed from attitude rate gyro outputs. The initial and final attitudes are assumed to meet the target criteria but this assumption has not been confirmed to date. These graphs will be updated with the actual reduced attitude histories when they are received at LaRC.

The predominant constituents of the upper atmosphere at 61-C orbital altitudes are molecular nitrogen and atomic oxygen, with molecular oxygen the third most abundant specie. Since atomic oxygen recombines on the SUMS inlet system surfaces, the sum of atmospheric O and O_2 will appear at the 32 AMU peak in SUMS spectra. The only peaks of interest are therefore 28 and 32 insofar as the atmosphere is concerned. Other atmospheric constituents are far below the SUMS detectable limit.

The reduced data for 28 and 32 AMU for the three 61-C orbital sequences are shown on Figures 6 through 8. None of the data sets shows any evidence of a rise in ion current around the

SUMS port zero angle of attack point, indicating that either the atmospheric density was too low or that SUMS was not open to the atmosphere. The signal levels in all cases are consistent with background levels seen in preflight tests.

3.0 SUMS 61-C Reentry Operations

The primary objective of the SUMS experiment is to measure the partial pressures of atmospheric species at the SUMS inlet port during reentry. These measurements can then be used to calculate dynamic pressure which combined with acceleration measurements from HIRAP allow the calculation of aerodynamic force coefficients for the Shuttle Orbiter. SUMS was designed to obtain data in the reentry phase where the aerodynamic flow transitions from free-molecular to continuum.

3.1 Reentry Sequence Description

SUMS operation during reentry is autonomous after the application of instrument power 2 hours before deorbit burn initiation. From this point on until power is removed after landing, SUMS is operating and providing data to the PCM. The PCM and recorder are turned on 5 minutes prior to deorbit burn initiation and remain on until after landing.

Power application to SUMS initiates the sequence and control logic which initially opens all valves (range, inlet, and protection) if the check for inlet pressure less than 5 torr is true. As descent occurs, the logic checks for three consecutive ion current peaks above 1×10^{-9} ampere and on this occurrence closes the range valve. The SUMS inlet pressure at which the range valve is closed is about 5×10^{-3} torr depending on dynamic lag of the inlet system. As the descent continues, the logic checks again for three consecutive peaks above 1×10^{-9} ampere and on the second occurrence closes the inlet and protection valves at an inlet pressure just under one torr. The instrument continues to output background spectra until power is turned off on the ground.

Figure 9 shows the predicted 28 AMU peak (nitrogen) response during reentry for an interval of about ±200 seconds around entry interface. The 28 peak ion current should rise to 10^{-9} ampere about one minute after entry interface at which time the range valve should close, increasing the pressure drop across the inlet system by a factor of 100. After the natural response transient damps out following range valve closure, the ion current rises again to 10^{-9} where the inlet valve should close. The 28 peak will control the range valve and inlet valve closures because it is the dominant atmospheric specie at altitudes near entry interface. The oxygen peak will behave similarly but will not reach the maximum current as the nitrogen peak will.

3.2 Flight Data Results from Reentry Sequence

Figure 10 shows the reduced ion currents for 28 and 32 AMU during the time from deorbit burn to almost 1000 seconds after entry interface. As with the orbital sequences, there is no indication of atmospheric gas in the mass spectra over this interval.

The SUMS engineering data showed all parameters were normal throughout the reentry sequence. All status flags were normal and all valves had been commanded open at the beginning of the sequence.

The range valve was predicted to close around 48557 seconds GMT or about 77 seconds past entry interface. No rise in the atmospheric gas peaks was noted before this time and the range valve closure was not indicated in the SUMS status data near this time. The inlet valve was predicted to close at 48690 seconds GMT and this operation was not indicated near the expected time either.

Figure 11 shows the reduced data from the SUMS inlet pressure transducer which has its pickoff point at the inlet port side of the inlet valve. The pressure is at background level up to 48600 seconds at which time it starts to rise, reaching the maximum of 5.4 torr at 48750 seconds. The SUMS sequence and control logic commanded all valves to close when the inlet pressure reached maximum to protect the system from excessive external pressure. Figure 11 indicates the time at which the inlet valve was predicted to close and the measured pressure at this time was quite close to the predicted value.

4.0 Variation in Background Levels

Comparison of background levels over the four sets of 61-C flight data (3 orbital, 1 reentry) shows some variations within the range of an order of magnitude. In some cases the background levels are nearly constant over the sequence; in others, a definite rise is noted. These variations pose the question as to whether SUMS may have been open to the atmosphere during one or more of the orbital sequences and may have been exposed to contaminants outgassing from the Orbiter or possibly to water vapor trapped in the inlet port in the launch pad environment.

Figure 12 shows the water vapor history for all four sequences. The ORB-1 sequence produced the highest H_2O background, 1.7×10^{-12} amperes, and was most nearly constant over the measurement interval. The ORB-3 sequence produced the lowest background, 2×10^{-13} to 3×10^{-13}, and had the largest variation across the measurement interval, about 50%. The ORB-2 and reentry sequences fall between these extremes, both in average magnitude and slope.

The background water peak is due to surface desorption of adsorbed water vapor and is temperature dependent. This process can also occur with other gases on a lesser scale. Figures 13 and 14 show the CO/N_2 (28 AMU) and CO_2 (44 AMU) histories, respectively, and clearly indicate the same general behavior as the water peak. The consistent behavior of these three peaks indicates that their gas source was internal background influenced by a common variable, temperature, and was not the external Orbiter environment.

No temperature measurement at the surfaces where desorption occurs is made. The nearby ion source temperature is measured but it is influenced primarily by the source filament dissapation and stabilizes more rapidly than surfaces such as the cap area. The cap area temperature could be influenced by warm-up time, among other factors, such that some correlation could exist between background levels and warm-up time.

ORB-1, ORB-2, and the reentry sequence were provided the full two hour warmup time before data acquisition started. The background peaks for these sequences are grouped fairly close together. However, power was applied to SUMS quite late in preparation for ORB-3 because of schedule pressures in the Orbiter operations. (Note: ORB-2 and 3 were inserted in the Orbiter mission operations during flight after the landing delay occurred.) The background signals for ORB-3 were considerably lower than the levels for the other sequences and show steeper slopes in the earlier portion of an exponential rise with temperature as expected. The variations in background levels appear to be caused by the combination of warmup time variations and ambient temperature variations.

5.0 Conclusions

Analysis of the SUMS 61-C flight data has been completed and clearly indicates a malfunction prevented the mass spectrometer from measuring any detectable gases entering the SUMS inlet port. The following observations and conclusions are evident from this analysis.

(1) There is no evidence of atmospheric or contaminant gases in any of the SUMS orbital measurements.

(2) There is no evidence of atmospheric gases during reentry.

(3) Analysis indicates variation in signal levels over a sequence or between sequences was due to internal surface temperature variations.

(4) SUMS sequence and control logic operated normally in closing all valves due to sensing high inlet pressure at low altitude during reentry.

(5) All engineering and status parameters were normal during all 61-C operations.

(6) The SUMS inlet port was not blocked as indicated by the inlet pressure transducer.

(7) The SUMS gas path appeared to be blocked between the inlet pressure transducer pick-off point and the mass spectrometer ion source.

(8) The most likely source of such blockage was a clogged filter or failed-closed condition of either the inlet or protection valve.

FIGURE 1 PREDICTED N2 AND O2 ION CURRENTS
SOLAR MINIMUM (61-C)

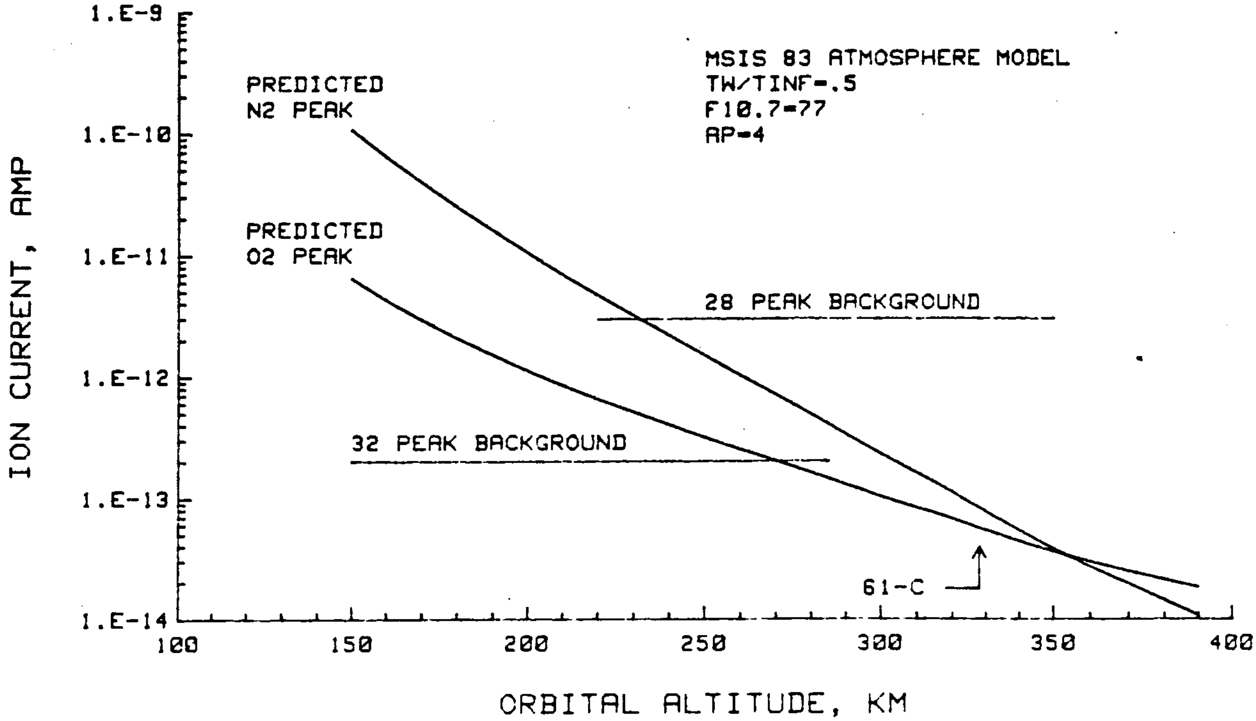


FIGURE 2 PREDICTED N2 AND O2 ION CURRENTS
SOLAR MAXIMUM

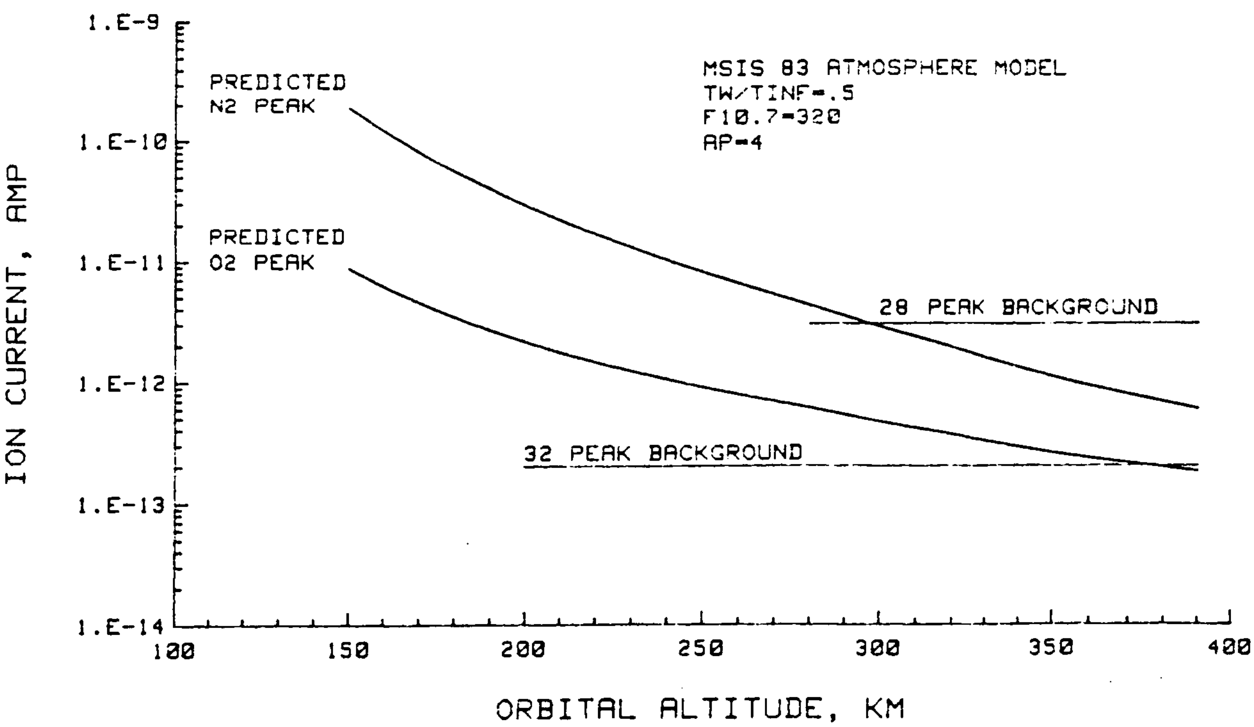


FIGURE 3 SUMS PORT ANGLE OF ATTACK, ORB 1

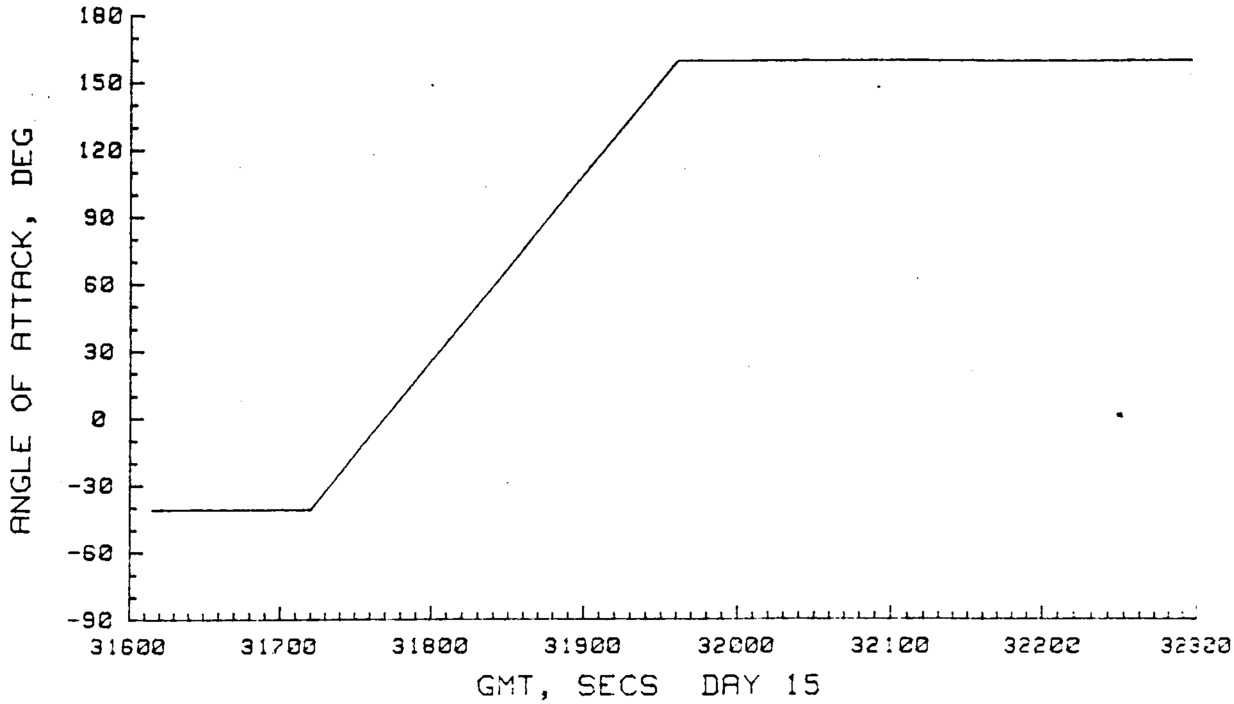


FIGURE 4 SUMS PORT ANGLE OF ATTACK, ORB 2

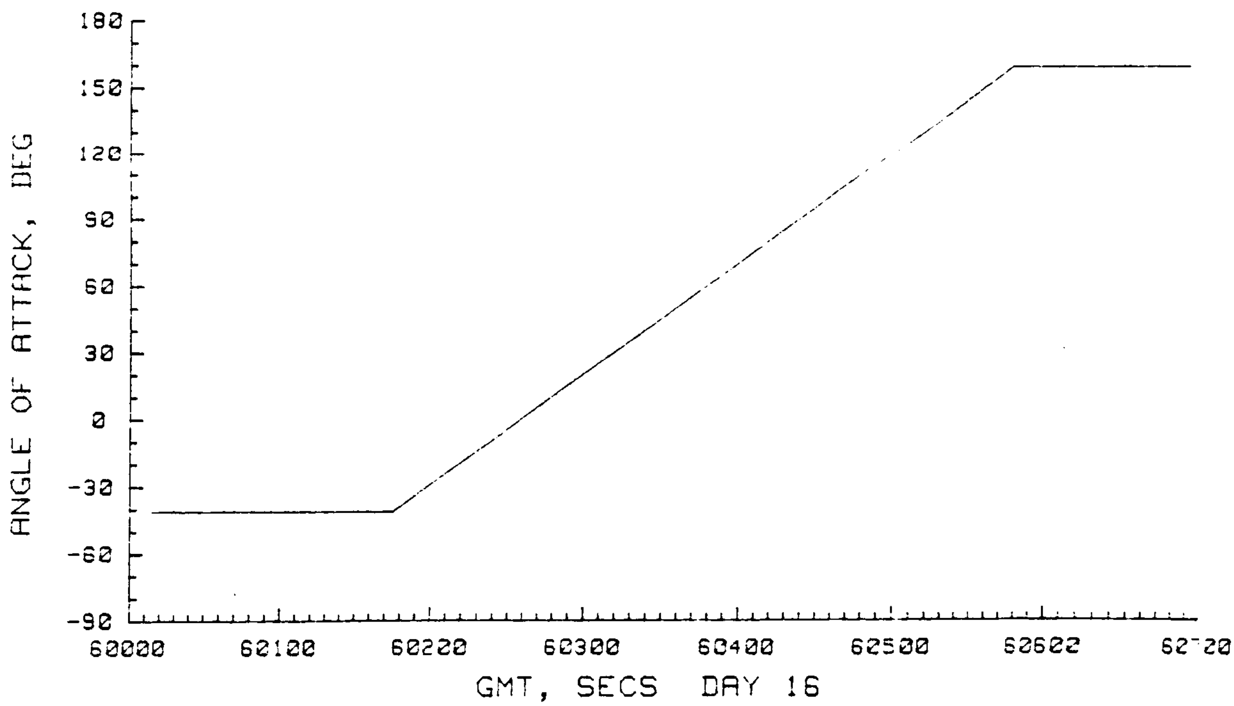


FIGURE 5 SUMS PORT ANGLE OF ATTACK, ORB 3

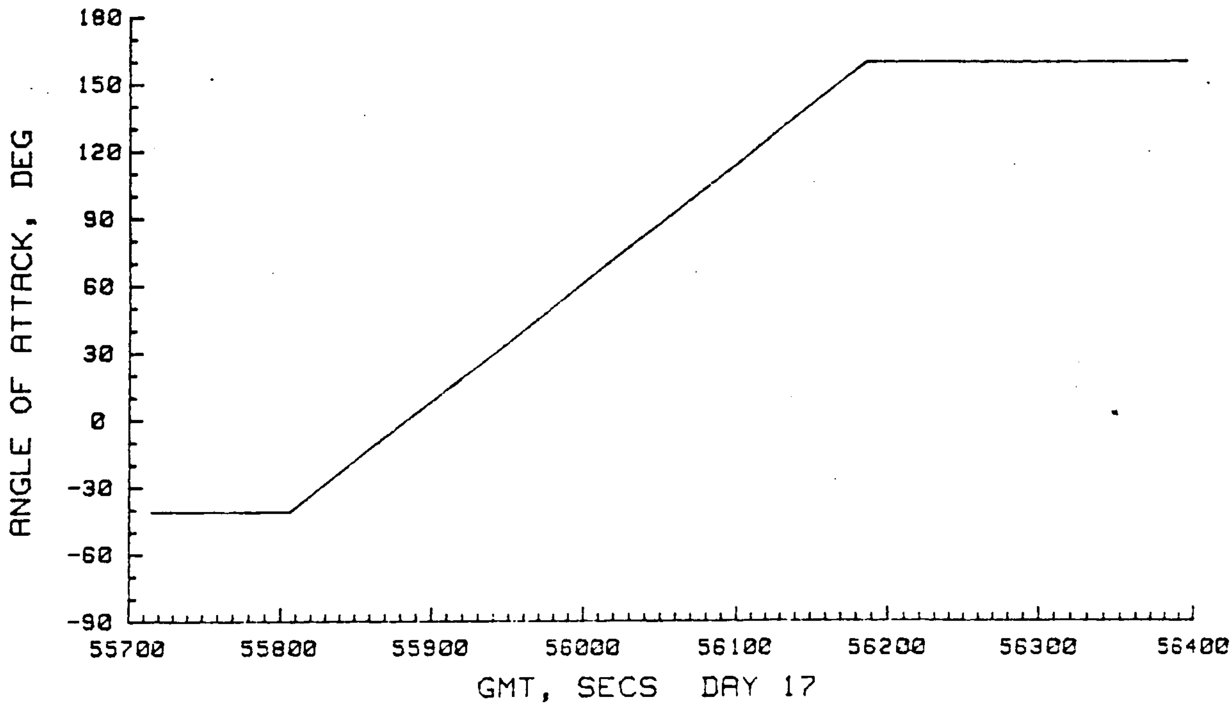


FIGURE 6 SUMS ORB-1 FLIGHT RESULTS

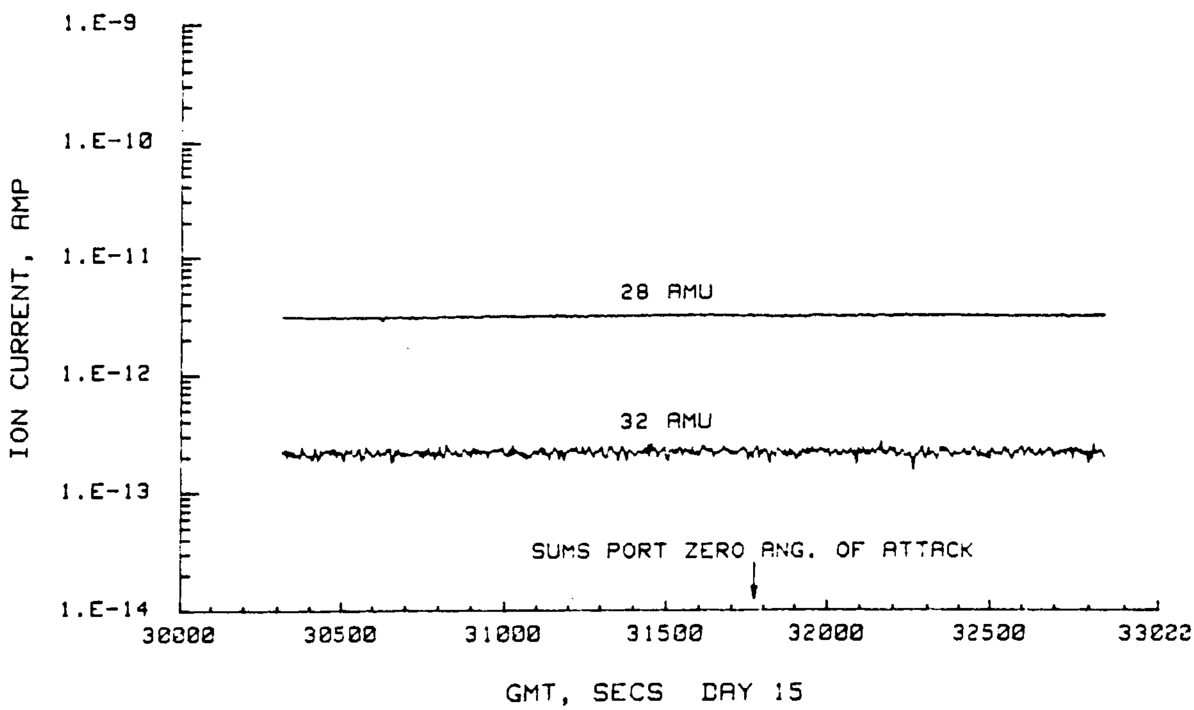


FIGURE 7 SUMS ORB-2 FLIGHT RESULTS

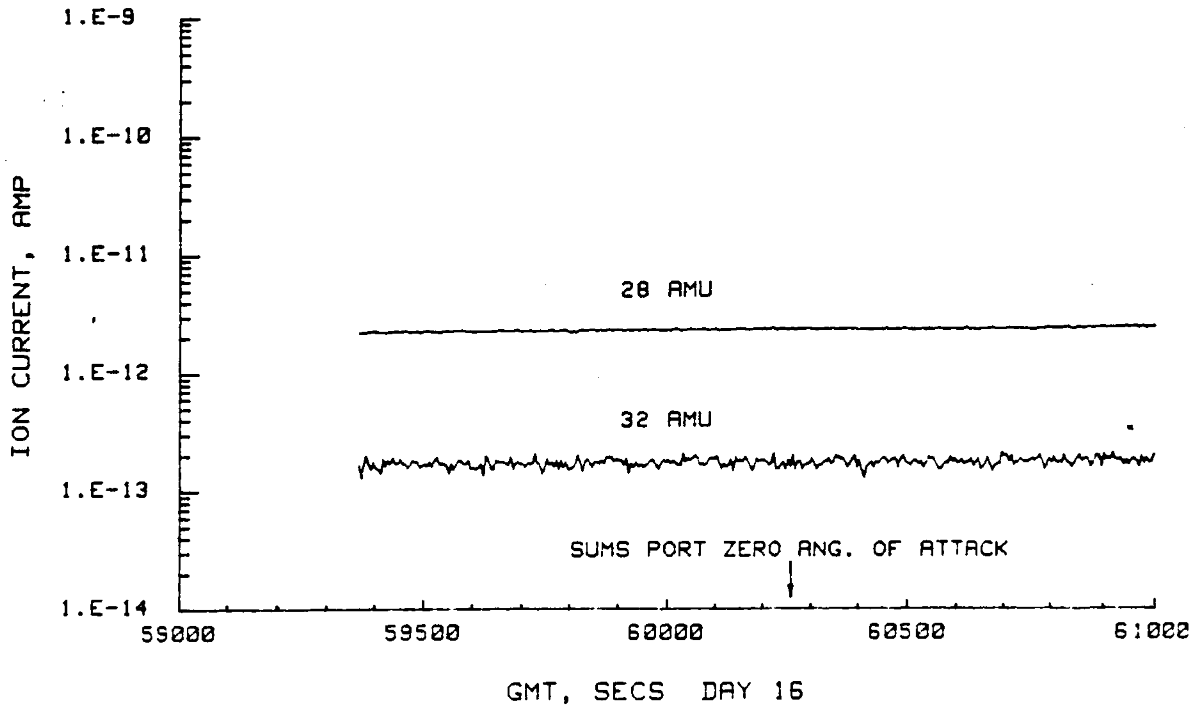


FIGURE 8 SUMS ORB-3 FLIGHT RESULTS

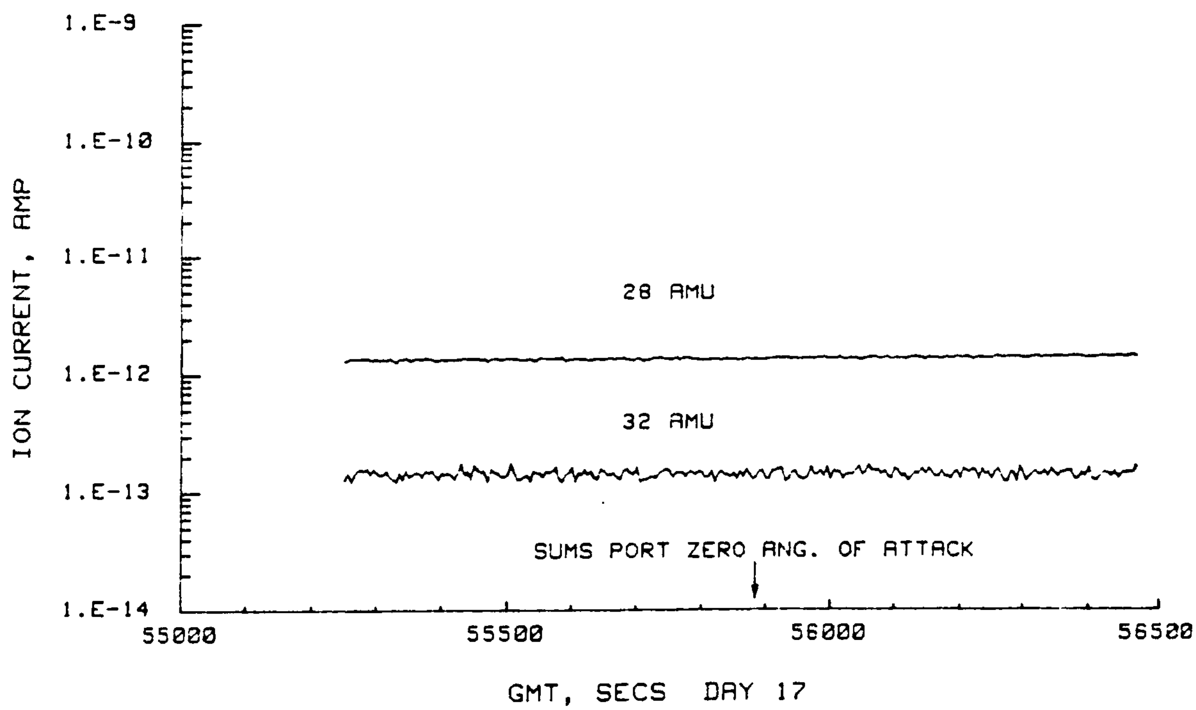


FIGURE 9 SUMS 61-C PREFLIGHT RESPONSE PREDICTION

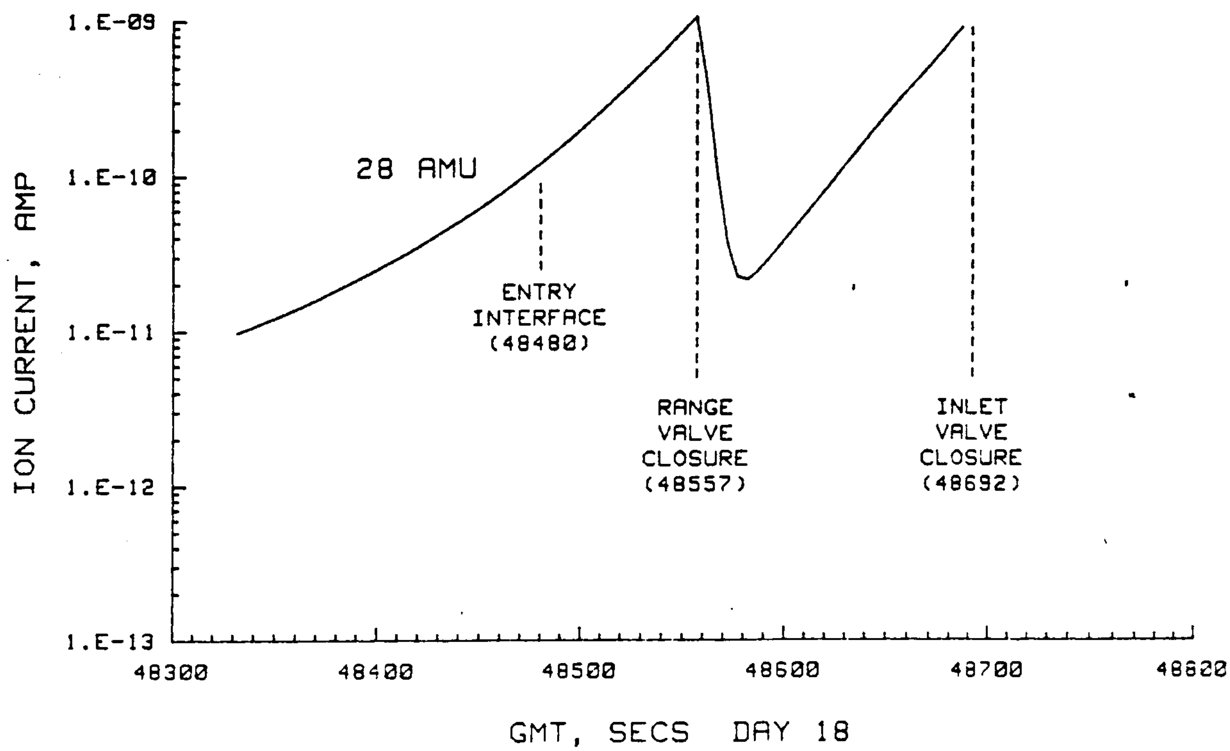


FIGURE 10 SUMS REENTRY FLIGHT RESULTS

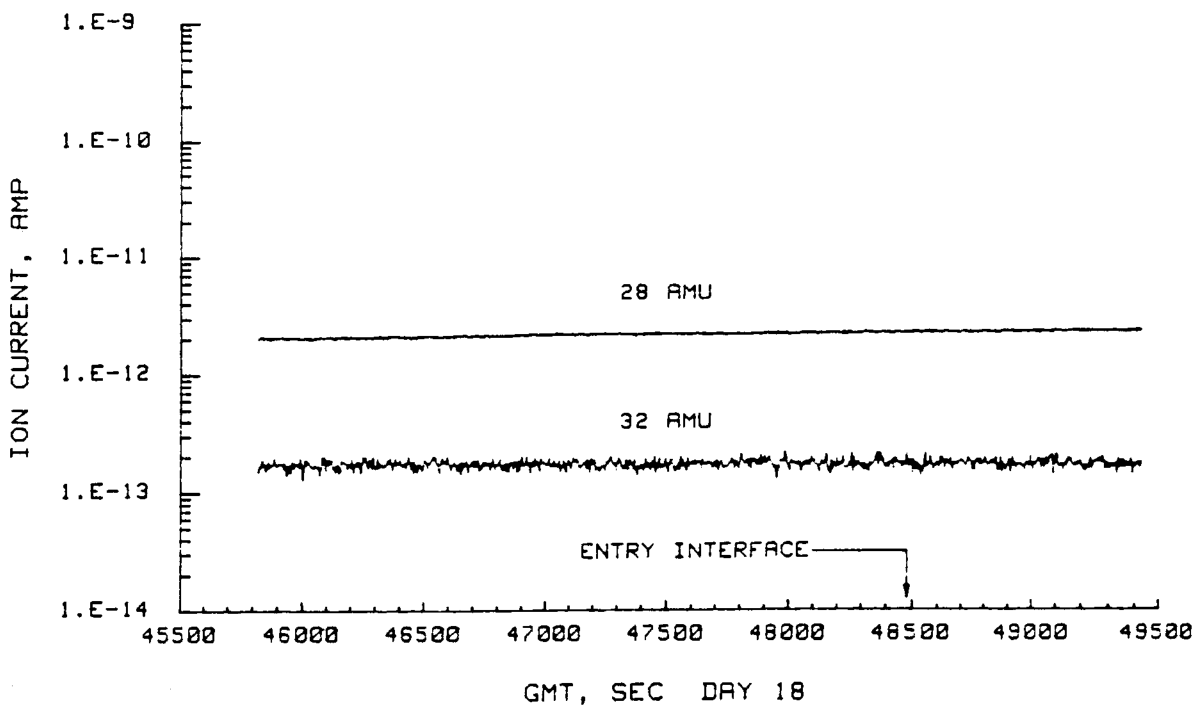


FIGURE 11 SUMS 61-C INLET PRESSURE

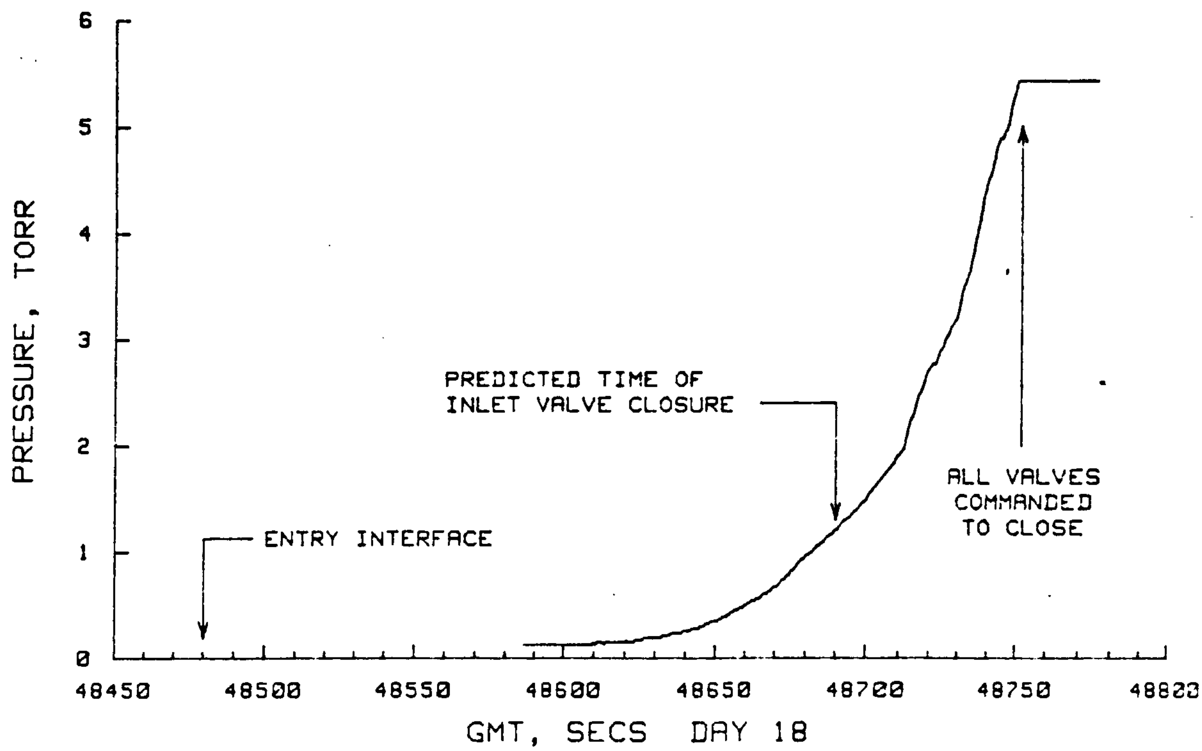


FIGURE 12 H2O (18 AMU) HISTORY

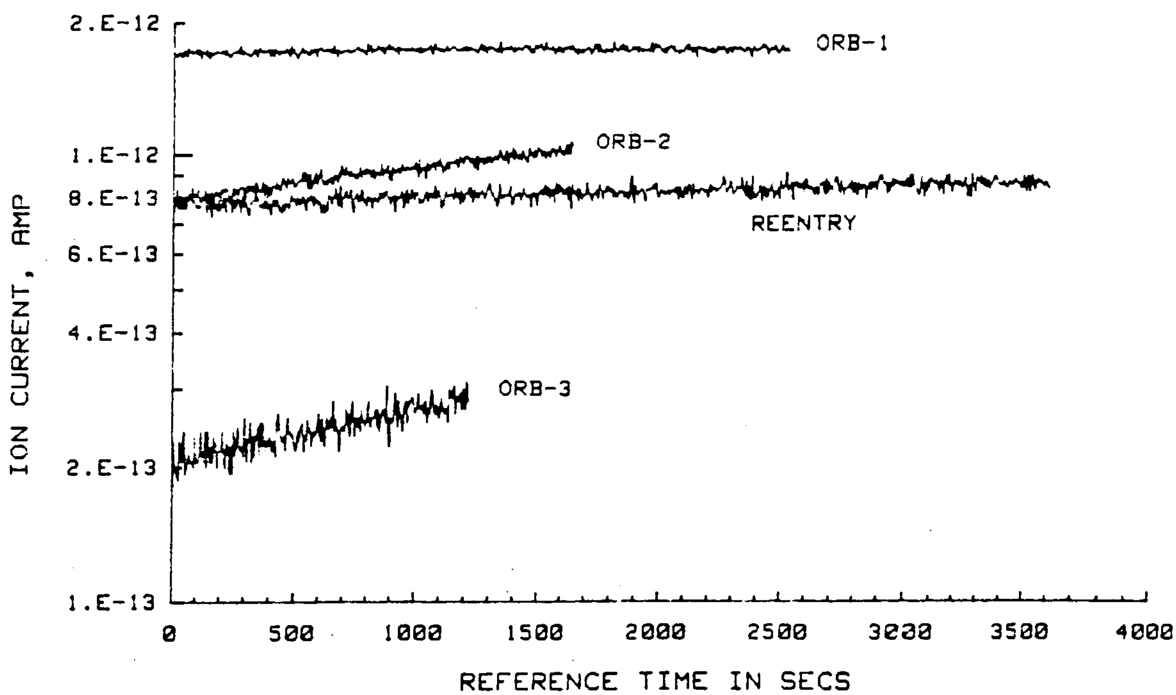


FIGURE 13 CO/N2 (28 AMU) HISTORY

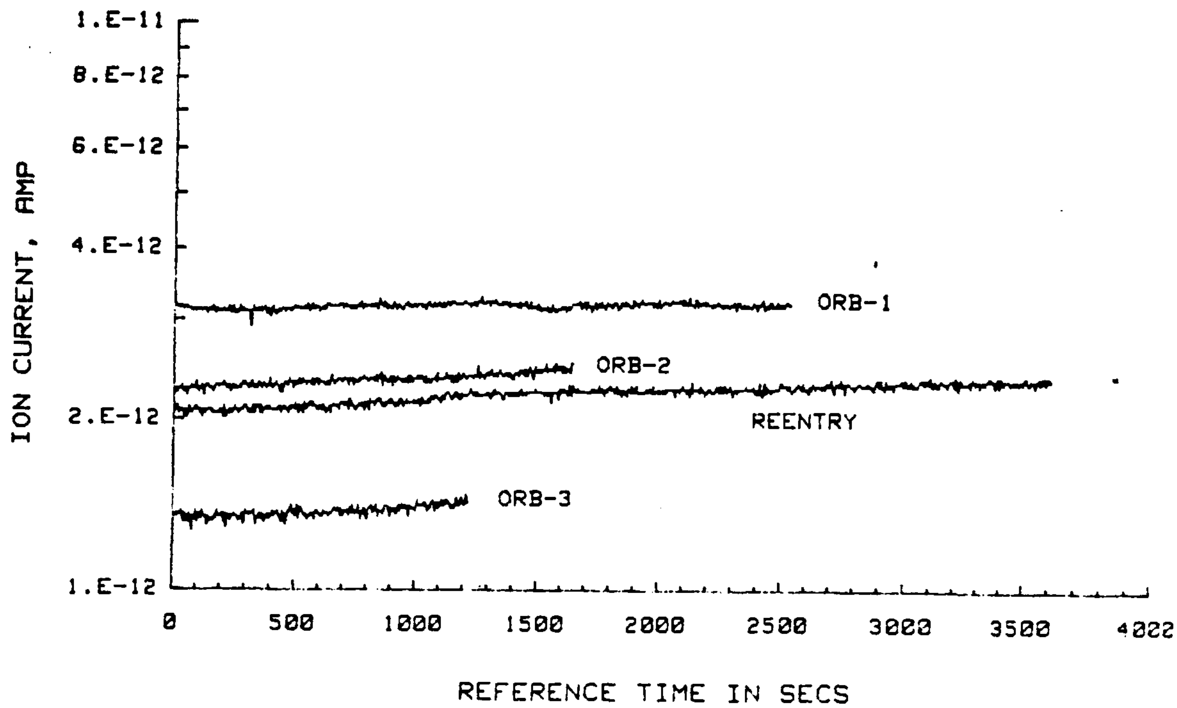
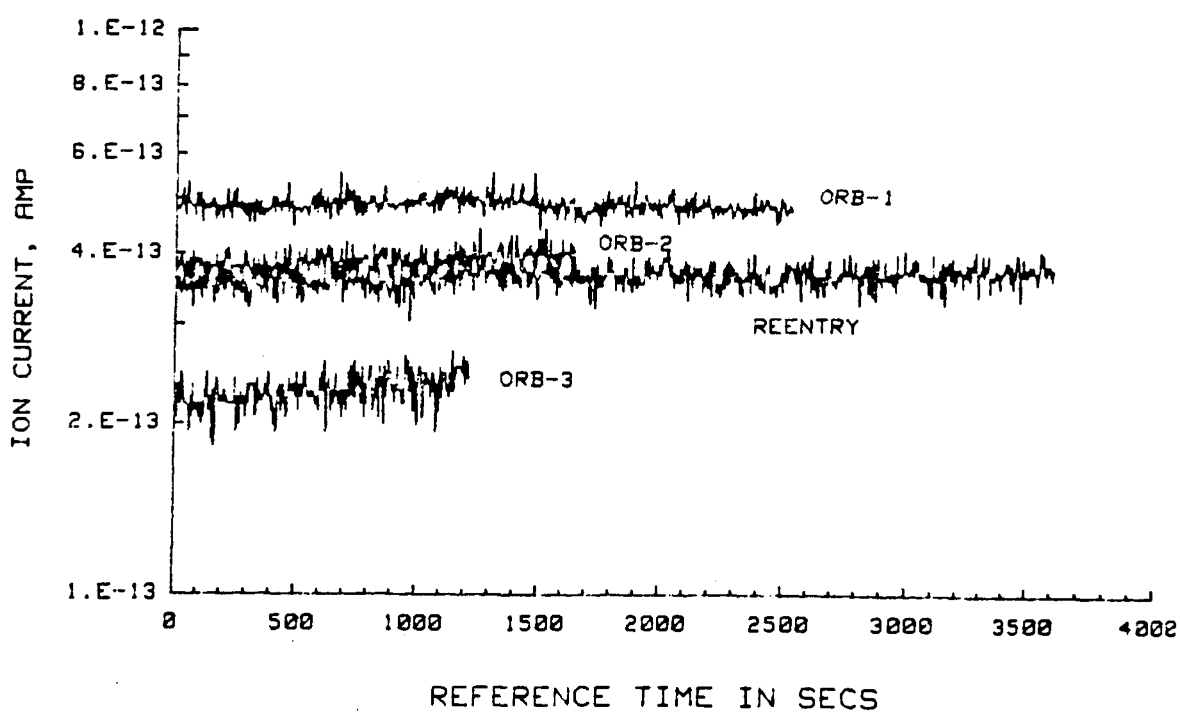


FIGURE 14 CARBON DIOXIDE (44 AMU) HISTORY



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16. Abstract

This report presents results and status of work performed under contract NAS1-16385, Phases II and III, covering software development and flight data analysis for the Shuttle Upper Atmosphere Mass Spectrometer (SUMS) experiment. A descriptive summary of the SUMS Flight Data Reduction and Analysis System (software) is presented, including details of the inlet reduction algorithm. Static and dynamic calibration test procedures are discussed and results of the tests are presented. A discussion of ongoing analysis efforts is included. The results of flight data analysis for the SUMS 61-C (STS-32) mission are attached to this report. This was the only SUMS flight during the contract period and failure of the protection valve caused loss of science data.

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